



DEPARTMENT OF
SCIENTIFIC AND INDUSTRIAL RESEARCH
GEOLOGICAL SURVEY AND MUSEUM

BRITISH REGIONAL GEOLOGY
NORTHERN ENGLAND

(THIRD EDITION)

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BRITISH REGIONAL GEOLOGY
NORTHERN ENGLAND

(THIRD EDITION)

by

T. EASTWOOD, A.R.C.S.

With some additions by F. M. TROTTER, D.SC., and W. ANDERSON, M.SC.

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NORTHERN ENGLAND

I. INTRODUCTION

AREA AND PHYSIOGRAPHY

THE REGION OF Northern England includes the whole of Northumberland, Durham and Cumberland, most of Westmorland, the Furness district of Lancashire, a little of north Yorkshire, and also the Isle of Man (*see Fig. 1*).

The dominant topographical and structural unit is the Northern Pennines, which makes its presence felt in a variety of ways. This tract of country now



FIG. 1. Map showing the area included in Northern England

forming a range of hills—for there are few mountains—is of considerable antiquity, and at various periods has influenced the deposition and arrangement of the rocks. From the maps it may be seen that the Northern Pennines chain separates the Lake District, with its fringing coal and iron fields, from the great coalfield of Northumberland and Durham, and that from its western side the New Red Sandstone swings from Edenside round the northern, western and part of the southern sides of Lakeland. Physiographically the Northern Pennines form the principal watershed; the rivers commencing on its eastern slopes flow more or less directly to the North Sea; those on the west, however, have been influenced by the dome-like uplift

of the Lake District which took place in Tertiary times and imposed upon the older rocks a more or less radial drainage that has persisted to the present day: this is perhaps best shown by the disposition of the lakes themselves in some of the river valleys.

Two depressions in the Pennine watershed are of considerable interest, both geologically and geographically. These are the Stainmore Pass, a broad upland hollow at the south end of Edenside between Brough and Bowes; and the low-lying Tyne Gap near Gilsland. Owing to the great pressure exerted by Scottish ice, both played a part in the glacial history of the district. Over the former, boulders of Shap granite were carried by ice contrariwise to the fall of the country, but the Tyne Gap is the more remarkable of the two in that the hills are completely breached, and in what was once a glacial drainage channel across the depression is now situated the shedding-line between waters flowing east into the Tyne and west into the Eden. Both these hollows serve as lines of communication from east to west for roads and railways; the Tyne Gap, however, provides the easier route, and since Roman times has been the more important; the famous wall from the Solway to Wallsend-on-Tyne lies immediately to the north of it.

The Northern Pennines have a sloping-desk structure (*see also* Fig. 3, p. 8); their western side rises abruptly from the snug, low-lying Vale of Eden by a step-like series of scarps, whereas the eastern side falls gently towards the North Sea, except near the Durham coast where the slope is broken by the prominent westerly-facing scarp of the Permian rocks. The eastern side, however, is deeply dissected by streams, and the topography of the area as a whole consists of flat-topped hills in sharp contrast to the well-rounded hills of the Cheviots along the Scottish Border. Cliffs are common along the eastern coast-line, and the low coastal plains of south-east Northumberland and Teeside form distinctive topographical features.

The beauties of the Lake District are too well-known to need description here, but attention may be drawn to the influence of the rocks on scenery. In the tract included between lines drawn through Ullswater via the eastern and southern sides of Derwentwater towards Ennerdale on the north, and through Conistone and Ambleside on the south, the rocks of the Borrowdale Volcanic Series give rise to the bold, craggy heights which include Helvellyn, the Scafells and Langdales, and the famous scree of Wastwater. These form a marked contrast to the smoother, less rugged Skiddaw Slate country to the north, and to the milder, pretty rather than grand, type of scenery to the south typical of the area occupied by the Silurian rocks.

Most of the valleys have been modified by the action of ice; Wastwater, the bottom of which descends below sea-level, is perhaps the best example of overdeepening; hanging tributary or side valleys are common and betray—by the amount of ‘hang’, or difference in level with respect to the main valley—the amount of material which has been removed locally by ice. All show, by the *roches moutonnées* and piles of glacial debris, that ice played a considerable part in imparting to the country its present outlines after its general features had been developed by subaerial agents of denudation.

The scenery of the surrounding rings of Carboniferous, Permian and Trias Sandstone rocks calls for little comment. Where not too heavily drift-covered the former give rise to bold escarpments of limestone, of which good examples may be seen near Grange-over-Sands, and the latter to pleasant

pastoral country, such as parts of the Vale of Eden. In the so-called Carlisle Plain the 'solid' rocks are masked by glacial drift, and the 'ridge and hollow' drumlin country there is almost entirely due to the transportive power of ice.

The Isle of Man, apart from the drift-covered plain in the northern quarter, is distinctly hilly, but all the hills betray by their rounded outlines that they have been overridden by ice. The rocky shores, however, abound in sheltered bays that combine with the rugged cliffs of the headlands to produce some magnificent coastal scenery.

GEOLOGICAL HISTORY

Let us now consider the geology of the region in so far as the varieties of rocks are concerned, and their relationship to one another. In the table below an attempt has been made to indicate the conditions under which deposits referable to certain *systems* of strata came into being during certain *periods*. A more detailed subdivision of the systems will be found in the sequel.

PERIODS	DEPOSITS	CONDITIONS AND EVENTS
POST-GLACIAL:	Blown sand, peat, alluvium, Raised Beaches, Submerged Forest	Relative changes in sea-level, small changes in climate
GLACIAL:	Boulder clays, sands and gravels <i>Unconformity</i>	Glacial Great erosion
?EOCENE OR MIOCENE:	Igneous dykes ? Deposition of lead, zinc and iron ores	Uplift of Lake District; much faulting
JURASSIC:	Shales and limestones	Marine
TRIASSIC:	Red shales and sandstones	Arid
PERMIAN:	Magnesian Limestone, shales, sandstones and breccias <i>Unconformity</i> Intrusion of Whin Sill	Arid Great erosion, gentle folding; isolation of coalfields
CARBONIFEROUS:	Shales, sandstones, coals (chiefly in upper part), limestones (lower part), conglomerates; basalts ? Deposition of tungsten ores	Deltaic and marine; some vul- canism
OLD RED SANDSTONE:	Granites and other plutonic igneous masses; lavas and agglomerates <i>Unconformity</i>	Volcanoes (in Cheviots) Great erosion. Severe folding
SILURIAN:	Shales and sandstones	Marine
ORDOVICIAN:	Shales (ashy in part) overlying limestones <i>Unconformity</i> Lavas and ashes (chiefly middle of period) Shales, grits and sandstones	Marine with some vulcanism and erosion Gentle folding Volcanoes (Lake District) Marine

Owing to denudation at different periods and to vagaries of deposition and structure all these rocks are not present in any one area. West of the Pennines there is a greater variety of rocks, both in type and in age, and a much more complicated structure, than to the east of that chain. To the west, for instance, the Ordovician and Silurian rocks were folded and

buckled, uplifted and eroded, and buried beneath newer sediments more than once before the dome was produced which ultimately by denudation gave us the Lake District. Some of the old rocks undoubtedly make up part if not all of the platform on which rest the Carboniferous rocks of Northumberland and Durham. We know little of them except in the Cheviots, but the great outbursts which piled up thousands of feet of volcanic rocks during Ordovician times in Lakeland are not known to have affected the district east of the Pennines. The Cheviot vulcanicity is of Old Red Sandstone age.

Let us now consider the events which gave us these rocks and disposed them in their present position, basing our description mainly on the Lake District.

The Skiddaw Slates are the earliest Ordovician beds exposed in this region. They represent muddy and sandy sediments deposited in a shallow sea. This tranquil period was followed by volcanic eruptions. Lavas, mainly andesites, were poured out in great profusion, but the locked-up energy of imprisoned vapours was frequently sufficient to blow already consolidated rocks and still fluid lavas into the air as fragments, some of which fell as fine-grained ashes or tuffs, while others formed agglomerates or breccias resembling very coarse concrete. These rocks constitute the Borrowdale Volcanic Series. The sites of the volcanoes are unknown, but they may have been somewhere about the centre of present-day Lakeland. When volcanic activity waned uplift and gentle folding, accompanied by some erosion of the volcanic rocks, took place before normal marine deposition set in again; this type of sedimentation continued till the end of the Silurian Period, though the Yarlside or Stockdale Rhyolite (p. 17) indicates a brief recrudescence of vulcanism towards the end of the Ordovician Period.

Movements of minor intensity, that took place during the time these rocks were being formed, are responsible for breaks in the succession, but the cycle of deposition closed with a great series of earth-movements (termed 'Caledonian'), and a continental phase—that of the Old Red Sandstone period—commenced. Compression from the north-west or south-east buckled the strata into saddles and troughs, or anticlines and synclines, which are still readily discernible despite the innumerable minor corrugations (see Fig. 2). The squeeze which caused this folding also induced the cleavage in some of the rocks which now provide roofing slates.

The uplift was accompanied or followed by the intrusion of vast amounts of igneous material. We now see, after repeated denudation, portions of what were then deeply buried igneous masses, viz. the granites of Shap, Skiddaw, Eskdale and the Isle of Man, the granophyre of Ennerdale and the granophyre-gabbro complex of Carrock.

One result of the upheaval was a change in climate; the land newly made from the sea-bottom became a desert encircling inland seas—the aridity possibly due to the lack of vegetation, for no land flora of any consequence was then in existence. Vulcanicity was again rife, and in the Cheviots we have the remnants of the volcanoes of this period.



A SEA-STACK OF WELL-BEDDED MAGNESIAN LIMESTONE,
TWO AND A HALF MILES SOUTH-EAST OF SOUTH SHIELDS



A.—SKIDDAW AND BASSENTHWAITE LAKE—SCENERY TYPICAL OF THE
SKIDDAW SLATES

(Reproduced by permission of Abraham's, Keswick)



B.—NORTH FACE OF SCAFELL—SCENERY TYPICAL OF THE BORROWDALE
ROCKS

(Reproduced by permission of Abraham's, Keswick)

Arid conditions, though not necessarily continuous, probably outlasted the time covered by the accumulation of the Old Red Sandstone itself, for it is certain that all the conglomerates, representing the offscourings of the land, are not confined to that period but are in many cases referable to the Carboniferous. We know that the deposition of the limestone and coal-bearing measures of the Carboniferous did not commence in all places at the same time. While the lower part of the Carboniferous formation was being laid down in Northumberland, in lagoons which communicated with the open sea perhaps in the vicinity of the present Solway Firth, the Alston region and much of the rest of Cumberland was still above the sea. This land was a peninsula extending across our district from Durham probably to the Isle of Man, with possibly an interruption along the line of the Vale of Eden. An open sea lay to the south over the site of Furness, with clear lagoons towards Ravenstonedale. Later on the peninsula was submerged, and sedimentation proceeded across the whole area with but comparatively minor interruptions until the Coal Measures had been laid down. During the latter part of this period open-sea conditions gave place to deltas and swamps with luxuriant vegetation that ultimately formed our coal seams; but towards the end the climate was again approaching arid, as is shown by the red, upper measures of Cumberland.

Volcanic eruptions during the earlier part of the Carboniferous Period are responsible for first the basaltic lavas of the Border region, then those of Cockermouth and lastly those of the Isle of Man. These indicate a westward shift of volcanic outbreaks during Lower Carboniferous times.

The Permian rocks rest unconformably on those of the Carboniferous, and in places (West Cumberland) transgress on to Borrowdale Volcanic rocks. In the interval represented by this unconformity the Pennines came into being; but they did not attain full growth till much later. This second continental phase also had its igneous activity, but in our district this was not on a large scale, though one type of rock—the dolerite of the Whin Sill and its associated dykes—is of wide distribution. The earth-movements at this period are also responsible for isolation of the coalfields, for the relatively minor folding and some of the faulting in those fields, and to some extent for the peculiarities of distribution and composition of the Permian and Triassic rocks. East of the Pennines we have the great mass of Magnesian Limestone, and the salt and anhydrite deposits of Middlesbrough, deposited in a 'dead sea' of Permian times. To the west the Magnesian Limestone is but feebly represented; in place of most of it we find thick red sandstones (Penrith Sandstone) and/or breccias (brockrams). The former betray their origin as desert sand by the presence of 'millet-seed' grains, while the latter appear to have been formed by rare torrential rains sweeping screes from the higher valleys into the lowlands as great fans of gravel. Some of these gravels debouched into lakes, where a thin Magnesian Limestone was deposited (e.g. Barrowmouth, near Whitehaven).

Subsidence brought in its train more stable conditions, and the St. Bees Shales, St. Bees Sandstone and Stanwix Shales were then laid down, in turn, in seas enclosed by deserts. At times these bodies of water dried up into

salinas in which calcium sulphate and sodium chloride were precipitated. Great lenses of these substances preserved in the midst of shales or marls furnish the salt of the Isle of Man and Walney Island and the gypsum and anhydrite of the Vale of Eden, Barrowmouth and Furness.

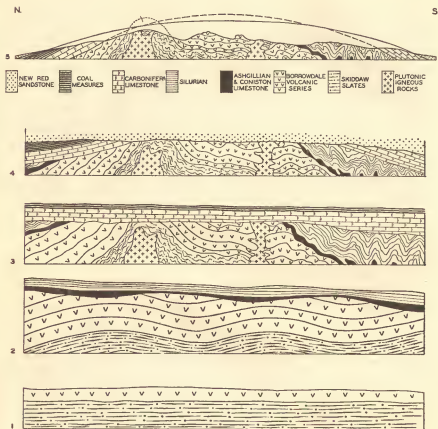


FIG. 2. *Diagrammatic sections to illustrate the building of the Lake District*

1. Deposition of Skiddaw Slates and Borrowdale Volcanic Series.
2. Slight folding; erosion; deposition of Coniston Limestone Series, Ashgillan and Silurian rocks.
3. Marked folding; intrusion of plutonic igneous rocks; intensive erosion; deposition of Carboniferous Limestone and Coal Measures.
4. Gentle folding; marked erosion; deposition of New Red Series.
5. Gentle uplift (producing an elongated dome and resulting in radial drainage); erosion to present form.

The arid conditions during Permian and Triassic times were somewhat inimical to life; the 'shell-fish' were stunted or deformed, and the plants few in kind; fishes and amphibians flourished elsewhere, and though the remains

of the former are locally abundant those of the latter appear to be rare in Northern England.

Near the end of the Triassic Period a widespread submergence resulted in invasion by the Rhaetic sea. From then onwards sedimentation continued for a prolonged period, but our direct record of the rocks laid down finishes with the Lias, found near Carlisle. Some of the later formations were probably deposited but were removed by denudation following the great earth-movements in Tertiary times. These movements gave rise to much of the faulting, and are mainly responsible for the arrangement of the rocks as we now see them. To them we really owe the Lake District, for they raised the rocks there into a great dome from which thousands of feet of the newer strata were weathered away, leaving outcrops of Triassic, Permian and Carboniferous rocks disposed around a core of already folded rocks (see maps and Fig. 2). The consequent radial drainage initiated on this dome has persisted, though the valleys, and the low ground generally, have been modified by the action of ice. Farther east the Pennine escarpment of Carboniferous Limestone rises from the low-lying New Red Sandstone. The latter is the younger formation, so the fault between them must be younger still. How much so we cannot say; but the movement was probably completed during Tertiary times, giving, after some denudation, a depression known as the Vale of Eden, formed of newer rocks lying between the raised block of limestone country to the east and the Lake District to the west (see Fig. 3).

As we have seen in the case of the Old Red Sandstone and Permian periods, crustal movements are generally accompanied by igneous activity. Elsewhere—in the west of Scotland and the Inner Hebrides, and in Northern Ireland—Tertiary igneous activity has been on a large scale and has included plutonic, hypabyssal and volcanic phases. In spite of the considerable movements affecting Northern England there are few indications of such activity to be found: the Cleveland-Armathwaite and the Acklington dykes of tholeiite are the best known representatives of the hypabyssal phase, though some of the small olivine-dolerite dykes of the Isle of Man are also referred to this period.

About the later geological history of Tertiary times we have no information, but with the Quaternary the district again attains prominence, though the story is too involved to be more than outlined here.

Under a copious and increasing precipitation of snow the country became hidden under a vast snow-field or ice-cap. Watersheds and even the earlier ice-sheds were overridden, largely due to the accumulation of ice in the northern part of the Irish Sea. The thickness of this ice may be gauged from the fact that Snaefell (2034 ft) in the Isle of Man was covered. Neither the waxing nor the waning of the ice was a regular process, for we have evidence of at least three glacial maxima with milder interludes—that between the second or main glaciation and the third being of sufficient duration to permit the growth of a peaty deposit at St. Bees. Boulder clay, boulders and striae on the solid rocks give the clues to the onward movement of the ice; retreat or melting stages are indicated by moraines and by outwash or melt-water gravels, some of which formed deltas in lakes impounded between the ice and higher ground already vacated, while other masses were thrown out on the

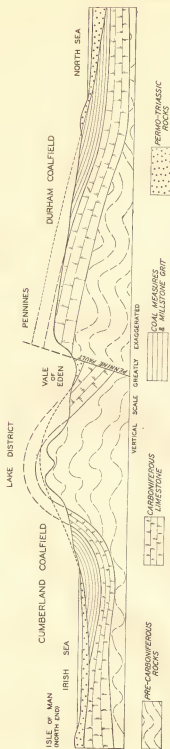


FIG. 3. *Diagrammatic section from the Isle of Man to the North Sea*

Note.—(i) The formation of the coal-basins due to pre-Permian folding, but the tilting of them due to post-Permian movements; (ii) the absence of Coal Measures in the Isle of Man; (iii) the movements, accompanied or followed by denudation, that have affected the Lake District; (iv) that the Pennine Fault, though here shown as largely post-Permian, was initiated at an earlier stage

land as fans. The dammed-up waters found escape over cols and soon cut sharply defined trenches that are now, as a rule, left as dry valleys across spurs, or are partly occupied by obviously misfit streams. There are numerous examples of these glacier-lakes, some of which were of brief while others were of longer duration; but as examples we may cite those from the Cheviots and the Wear in the east, and from the Black Combe district near Millom, the ancient Lake Carlisle and its predecessors in Edenside, and last but not least Glacier-lake Ennerdale, which is shown by deltas and by overflow channels to have been hundreds of feet deeper than the present lake.

In the western half of our district there was a great struggle between the native ice and that emanating from the south-west of Scotland—which, since it was a large contributor to that particular reservoir, is often spoken of as Irish Sea Ice.

The eastern part of our region also suffered an invasion by foreign ice—that from Scandinavia—which at an early stage impinged on the coast of Durham, and at a later stage deflected the native ice coastwise and southward.

The north of England is still colder than the south, but the difference was more marked during the Glacial Period. Prehistoric man was hunting and using unpolished implements made of flint (usually termed palaeoliths) in southern England while the north was still largely buried under ice, though some explorers probably ventured in during the milder intervals.

Our first post-Glacial deposit belongs to the Submerged Forest period, and patches of this forest with tree stools and logs occur between tide limits to the north of Maryport and at Drigg in Cumberland, in Furness, in the Isle of Man and on the north-east coast between Howick and Teesmouth. The present position of these relics indicates relative depression of the land to the sea, for trees cannot grow in such situations; the submergence was even greater than at first sight appears to be the necessary minimum, for the more recent adjoining land in Cumberland is made up of raised-beach gravels and warp clays, which show that the sea-level formerly stood about 30 ft above present O.D. The latter deposits are usually referred to as the 25-Ft Raised Beach. Relics of man in the form of Neolithic polished stone implements are rare on the mainland but are fairly abundant on the Raised Beach in the northern part of the Isle of Man.

The Irish Elk *Cervus giganteus* and the ox *Bos longifrons* flourished at this time; some of the marls below peat in the Isle of Man are famous for remains of the former. From the poverty of the Manx post-Glacial fauna and flora it has been suggested that the last connexion of the island with the mainland was during Glacial times.

From the Neolithic Age through the Bronze Age to historical times is but a step. During this interval there have been minor changes of sea-level and in the details of the coastlines, some of the ponds and lakes have silted up, blown sand has accumulated into dunes, and the rivers have deposited alluvium, but these changes have been small and are still going on.

ECONOMIC PRODUCTS

The economic products of this region are many and varied. Coal has become of increasing importance since the Middle Ages. The use of peat as fuel has greatly declined, but some is dug for moss-litter. Much of the iron was obtained in former days from the clay ironstones in the Coal Measures, and the mining of haematite on a large scale is comparatively modern. Small deposits of haematite occur in the pre-Carboniferous rocks of the Lake District and the Isle of Man, but the large irregular masses that result from the metasomatic replacement of limestone by iron-ore are confined to West Cumberland and Furness. For the non-ferrous minerals the Lake District hills were actively prospected by German miners under licence from Queen Elizabeth, and a copper industry was established at Keswick and at Coniston. Lead-ores on both sides of the Pennines also received attention—partly on account of their silver content—at an early date, but the value of the accompanying zinc-sulphide or blende was not appreciated until recent years. Attention may be drawn here to the peculiarities in their distribution; west of the Pennines the productive veins are confined to the older strata, the newer rocks such as the Carboniferous Limestone being barren of lead and zinc ores; east of the Pennines the Carboniferous Limestone is the chief repository, the limestone measures from the Great Limestone downwards being the most prolific in lodes and associated flats.

Wolfram and scheelite, the ores of tungsten, occur in quartz veins in the greisen at Carrock Mine, Cumberland, along with other minerals of the so-called pneumatolytic suite, though cassiterite or tin-stone is not present.

Ores of many other metals occur in the Lake District, such as cobalt, antimony, bismuth, gold and manganese, in addition to a great variety of mineral species, but are in too small quantities to be of any account.

Amongst the non-metallic minerals, the graphite of the Borrowdale Black-lead or Wad Mine, on which was founded the pencil industry of Keswick, was famous in the nineteenth century, but is now worked out. The barium minerals, barytes and witherite, either separately or associated with lead-ores, are of considerable importance in the paint and chemical trades. Both are mined in the limestones on or east of the Pennines, but only barytes is of commercial value in the Lake District. Attention may also be drawn to the occurrence of these minerals in the Coal Measures of Durham, where they were mined from a fault-vein at Brancepeth Colliery and have recently been got at South Moor.

Fluorspar, which is chiefly used as a flux, is rare in the Lake District, but is commonly associated with lead ore in the Northern Pennines. In the northern part of this orefield, embracing Alston Moor, Allendale, and Weardale, the fluorspar lies in an inner zone which is almost surrounded, first by an intermediate zone in which barytes and fluorspar are present, and second by an outer zone in which barytes and witherite are predominant.

Gypsum for plaster-making is mined in the Vale of Eden, and was formerly obtained at Barrowmouth, near Whitehaven. The other form of calcium sulphate, anhydrite, is raised at Billingham, near Stockton-on-Tees.

Salt, frequently associated with gypsum-bearing rocks, is obtained near Middlesbrough and in the Isle of Man ; it also occurs in Walney Island, near Barrow.

The limestones are quarried for use as a flux in the production of iron and steel and for agricultural purposes either as ground limestone or, after conversion by burning, as lime ; the Whin Sill, the granites and the limestones provide road-metal ; shales and clays, chiefly from the Coal Measures, are in demand for brick-making, both for building and refractory purposes ; and here we may mention the deposit of diatomite or diatomaceous earth occupying the site of an old lake at Kentmere, near Kendal.

Many kinds of rocks are used for local buildings, but the better ones are usually sandstones ; these include the Fell Sandstone of Doddington, the St. Bees Sandstone and the Penrith Sandstone, the last being also in demand for kerb-stones ; attention may also be drawn to the Newcastle Grindstone. The green slates of Coniston, Tilberthwaite, Elterwater, Borrowdale and Honister all belong to the Borrowdale Volcanic Series ; the blue slates of Kirby in Furness are well-cleaved Silurian sediments. The chief ornamental stone is the well-known Shap granite, but the black marble of Poolvash in the Isle of Man, the mottled marble of Dalton and the black marble of Frosterley in Weardale have also been used.

PREVIOUS WORKERS

Many notable geologists have been attracted to Northern England. Beginning with the Geological Survey, we are indebted to W. T. Aveline for many beautiful maps of the southern Lake District, to J. C. Ward and J. G. Goodchild for their labours in and around Lakeland, and to G. W. Lamplugh for his work in the Isle of Man ; east of the Pennines D. Burns, C. T. Clough, W. Gunn and H. Miller jun., are outstanding figures. Of men with local associations we may mention J. Otley, J. D. Kendall, and J. Postlethwaite in and around the Lake District, and G. A. Lebour, D. Woolacott and W. Forster in East Cumberland, Northumberland and Durham. No work dealing with the Lake District would be complete without reference to the names of A. Sedgwick and J. E. Marr ; the mention of 'igneous rocks' immediately recalls the names of A. Harker and R. H. Rastall, while 'Carboniferous' brings to mind the valuable work of E. J. Garwood, G. Tate, E. A. N. Arber, R. Kidston and S. Smith ; with the Permian we associate Sir R. Murchison, R. Harkness and C. T. Trechmann, and with graptolites Miss G. L. Elles.

Up to this point the district as a whole has been dealt with in very general terms. In succeeding sections a description of the various groups of strata will be given, beginning at the oldest, the Ordovician rocks, and closing with the recent formations. For the preparation of this account most of the matter dealing with Northumberland and Durham was supplied by Mr. R. G. Carruthers. The author begs to acknowledge, too, the help of his colleagues, Dr. F. M. Trotter, Dr. S. E. Hollingworth and Mr. W. C. C.

Rose, who prepared much of the exhibit in the Museum and the original drawings from which many of the text-figures have been made, and of Dr. C. J. Stubblefield and Dr. R. Crookall, who are responsible for the palaeontology.

Advantage has been taken of the issue of this third edition to incorporate some results of recent investigations ; for example, the fuller knowledge now available regarding the Coal Measures on both sides of the northern Pennines and additional information on the Permian evaporite deposits of Durham. Dr. F. M. Trotter is responsible for minor alterations in the text relating to Cumberland, Westmorland and Furness, and Mr. W. Anderson for those dealing with Northumberland and Durham.

II. ORDOVICIAN SYSTEM

THE ORDOVICIAN ROCKS of Northern England are divisible as follows:

Ashgill Series
Coniston Limestone Series
Borrowdale Volcanic Series
Skiddaw Slate Series

Skiddaw Slate Series.—The base of the series is unknown, and contortion and folding make it difficult to estimate the thickness exposed, but this probably amounts to several thousand feet.

The rocks comprise grits, flags, shales and mudstones. Several attempts have been made to subdivide the series by means of lithology, but the order of succession is not clear. Some of the rock-types have received local names—such as Blake Fell Mudstones, Loweswater Flags, Kirkstile Slates, Mosser Slates, Watch Hill Grit, Skiddaw Grit, Latterbarrow Sandstone—and at one time were considered to indicate definite horizons; but, apart from the last-named, the bulk of the coarser sediments are now believed to be low in the sequence, while of the finer-grained types the Blake Fell Mudstones probably owe their light-grey colour, minute spotting, and resonant properties to local alteration rather than to original character.

Although of little value as determinants of horizon, these local names serve a useful purpose in distinguishing various rock-types; thus the 'Kirkstile Slates' are dark shales, and such lighter grey bands as they possess are thin and widely spaced, whereas the 'Mosser Slates' are usually striped rocks made up of thin alternations of light silts and dark grey-green clayey material. Transitional types between Kirkstile and Mosser Slates occur; the latter also pass by increase of sand content into thin alternations of sandstones and shales, and these through flags and sandstones into grits. Some of the grits are very coarse and are occasionally pebbly.

The Latterbarrow Sandstone is a compact partly quartzitic rock similar to the higher part of the grit-belt of Watch Hill, near Cockermouth. At Latterbarrow, near Egremont, the rock is succeeded by the tuffs at the base of the Borrowdale Volcanic Series.

In addition to their main outcrop in the Lake District, the Skiddaw Slates are exposed in Black Combe and the Crossfell Inlier on the western side of the Pennines (*see* Fig. 4). They are believed to have been penetrated also beneath the Carboniferous Limestone in a boring at Crook in County Durham. Somewhat similar rocks form an inlier amidst the Carboniferous Limestone strata in Upper Teesdale where there are several exposures near Langdon Beck.

The Manx Slates of the Isle of Man were thought by Lamplugh to be equivalent to the lower and largely concealed part of the Skiddaw Slates.

Here, too, the order of succession is uncertain, but the upward sequence appears to be: Lonan Flags, Agneash Grits, Barrule Slates. No fossils of diagnostic value have been found, and by some authors, including Lamplugh, the rocks are referred provisionally to the Cambrian System. Some of the Manx Slates have been broken up and re-cemented into remarkable crush conglomerates or fault-breccias.

Although the Skiddaw and Manx Slates have been subjected to intense compression, the term 'slates' is rather a misnomer, for they rarely yield material for roofing.

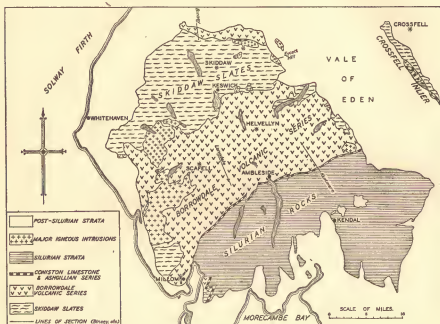


FIG. 4. Sketch-map showing the distribution of the pre-Carboniferous rocks of the Lake District

Fossils are not abundant in the Skiddaw Slates. They are mostly seen in the 'slates'. Perhaps the commonest is the shrimp-like *Caryocaris*; trilobites such as *Cyclopyge*, 'Phacops' and 'Placoparia' are rarely found but the most important fossils are the graptolites.

These lowly forms of life (see Fig. 5) are the principal zone-fossils of the Ordovician and Silurian rocks, and when fully represented permit of fairly close comparison of one area with another. In so far as the Skiddaw Slates are concerned there is some doubt as to the detailed application of the standard zonal sequence of the Ordovician graptolites. Mr. E. E. L. Dixon (in Whitehaven Memoir) regards the fauna of the Skiddaw Slates as comparable with that of the Lévis Shales of North America. He points out that several types of graptolites characteristic of different zones elsewhere in Britain occur close together, and he considers that the evidence favours

co-mingling rather than the close association of the different faunas of the zones by the attenuation of the sediments. Thus, at Barf, on the west side of Bassenthwaite Lake, where bryograptids, clonograptids, tetragraptids, extensiform didymograptids and tuning-fork didymograptids are found on scree, Dixon would regard the forms as a co-mingled fauna; although elsewhere, notably in Wales, the forms would represent the series of zones from the lowest Arenig to the *Didymograptus bifidus* zone of the Llanvirn Series. Dr. Gertrude L. Elles (in *Summary of Progress for 1932*), however, maintains that Mr. Dixon is mistaken in his interpretation of the evidence

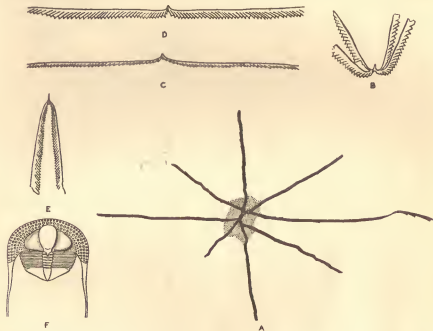


FIG. 5. Ordovician fossils (All natural size)

Skiddaw Slates (drawing after Elles and Wood).—A, *Dichograptus octobrachiatus* (Hall); B, *Tetragraptus serra* (Brongniart); C, *Didymograptus extensus* (Hall); D, *Didymograptus hirundo* Salter; E, *Didymograptus bifidus* (Hall).

Drygill Shales.—F, *Cryptolithus* [*Trinucleus*] *concentricus* Eaton *sensu lato*.

provided by the Skiddavian graptolites and sets out the following zones, which she further divides into subzones:

Didymograptus bifidus
Didymograptus hirundo
Didymograptus extensus
Dichograptus
Bryograptus kjerulfi

Borrowdale Volcanic Series.—The Skiddaw Slates are succeeded by strikingly different rocks, made up of lavas, tuffs and agglomerates, with some igneous intrusions; these are known collectively as the Borrowdale Volcanic Series; they total about ten thousand feet in thickness. The junction between the two series appears in some places to be a fault or a thrust; in

others it may be an unconformity ; and in certain areas—where lavas occur in slates—there appears to be a passage.

The lavas are mainly andesites ; some of them, particularly in the lower portion or Eycott Group of Marr and Harker, contain large crystals of feldspar, while others are fine-grained. Rhyolites also occur at various horizons, but are more abundant in the upper part of the series. Some of the rocks which are termed rhyolites are really intrusive. The central parts of the lavas are usually massive, whereas the upper parts are commonly vesicular, even when coarsely porphyritic. Flow-banding is often developed, and auto-brecciation, due to the welding of broken congealed crusts by still molten lava, is widespread ; many such rocks have been mistaken for coarse tuffs or agglomerates.

The fragmentary rocks resulting from explosive eruptions vary from very fine-grained tuffs, probably sorted by and deposited in water, to coarse agglomerates or breccias with lumps of rock a foot or more in diameter. Lateral pressure, to which all these old Lake District rocks have been subjected, has converted some of the tuffs into slates suitable for roofing. Such slates are particularly well developed in the Borrowdale and Conistone regions ; many of them show alternations of coarse and fine bands on the same slab.

Both lavas and tuffs contain garnets, but that mineral is particularly abundant in the middle part of the series.

The main outcrop traverses the central part of the Lake District (*see* Fig. 4, p. 14), but the Series also appears in force in the Caldbeck Fells on the north side of the Skiddaw anticline, and the Cross Fell Inlier forms the easternmost exposure. The Series has never been met with east of the Pennines and is unknown in the Isle of Man.

From the very nature of the rocks a uniform succession throughout the Lake District is scarcely to be expected ; thus, as pointed out by W. T. Aveline, lavas or tuffs prominent at one locality may be absent a few miles away ; on the other hand, some of the rocks appear to be remarkably constant in their occurrence.

Marr and Harker, and J. F. N. Green, have published general sequences considered to be applicable to the whole region, but detailed work by J. J. Hartley and G. H. Mitchell has shown that great variations occur from place to place. A threefold division into (1) a lower group of lavas predominantly andesitic but with subordinate bands of tuffs, (2) a middle group of tuffs with subordinate lavas, and (3) an upper group of lavas consisting of andesites below and rhyolites above, would appear to be generally applicable. However, these major groups vary rapidly in thickness and in character from place to place.

Since exact correlation of separated regions is at the present time impossible, sections are given (Figs. 6 and 7) to show local sequences, and structures. It will be noted that those of the northern outcrops exhibit a comparatively simple structure, while those of the south show much folding.

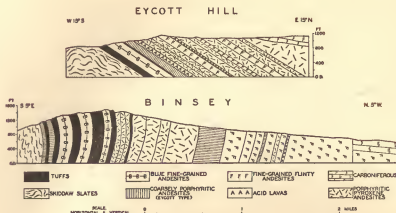


FIG. 6. Typical sections across the Borrowdale Volcanic Series: Northern area

No fossils have been found in these rocks, but their general equivalence to the Llandeilo of Wales may be indicated by their position between the Skiddaw Slates and the Coniston Limestone Series.

Coniston Limestone Series.—This series in part represents the Caradoc rocks of other parts of England; it is a group of calcareous sediments rather than measures characterized by good limestones, though some such rocks do occur occasionally. The series rests unconformably on the Borrowdale rocks, as shown by Mitchell, and a second unconformity, accompanied by overstep, can be detected at a higher level within the rocks in the Kentmere area (see Fig. 8). That volcanicity had not ceased entirely is proved by the presence of a rhyolite within the Coniston Limestone Series, while relics of such phases are not wanting in even higher Ashgill Series at Cautley, near Sedbergh.

The series is usually divided into two stages, of which the lower appears to be fully represented only in the fells bordering the Pennines to the east of the Lake District.

Coniston Limestone Series

	Thickness Ft
Sleddale Stage	Appelthwaite Beds: calcareous very fossiliferous shales with some ashy sediments and limestones 100 to 400
	Conglomerate, with pebbles of the underlying rhyolite (in places this conglomerate rests directly on the Borrowdale Volcanic Series, as in Kentmere) 10
	Yarlside or Stockdale Rhyolite 0 to 450
	Stile End Beds: stratified coarse and fine calcareous ashes with abundant but poor fossils; a conglomerate at base where resting on Borrowdale Volcanic Series 50 to 250
Roman Fell Stage	The <i>corona</i> Beds of Dufton Fells: calcareous shales with <i>Trematis corona</i> 100

At Dufton Fell, to the north-north-east of Appleby, the *corona* Beds are succeeded by the Dufton Shales, which represent the whole of the Sleddale stage; while in another outlier, at Carrock Fell to the north-east of Keswick, the Drygill Shales may be equivalent to low beds in the Coniston Limestone Series.

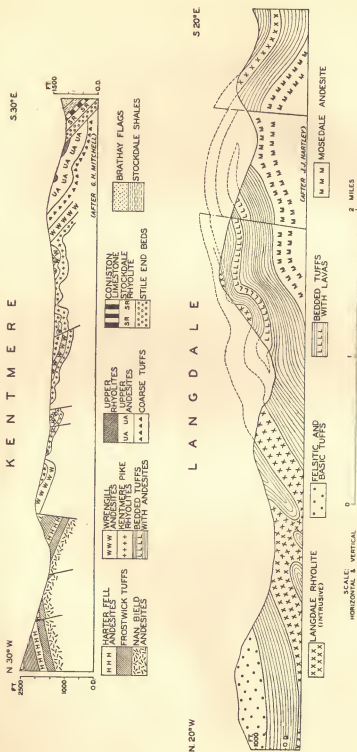


Fig. 7. Typical sections across the Borrowdale Volcanic Series: Southern area

In view of recent work (King and Williams, 1948) the Applethwaite Beds should probably be referred to the Ashgill Series; they are characterized by Orthid and Strophomenid brachiopods and by such trilobites as *Acidaspis*, *Calymene*, *Chasmops*, *Harpes*, *Iliaenus* and *Tretaspis*.

Ashgill Series.—The Ashgill Series is about 100 ft in thickness, and succeeds the Coniston Limestone Series with perfect conformity. At, or near, the base is a white limestone, about 12 ft thick, named after the type locality of Keisley in the Cross Fell Inlier, but often referred to as the *Staurocephalus* Limestone from its typical trilobite *Staurocephalus*. In the succeeding Ashgill Shales the lower portion is distinctly ashy and not very fossiliferous, but fossils, chiefly trilobites and gastropods, are abundant at higher levels. These shales form a marked contrast to the overlying, conformable, graptolite-bearing Stockdale Shales, which are taken as the base of the Silurian.

III. SILURIAN SYSTEM

THE STOCKDALE SHALES conformably succeed the Ashgill Shales in the Lake District, the advent of the newer strata being soon followed by the appearance of *Monograptus* (see Fig. 9).

The principal subdivisions are as follows:

Silurian System

		Thickness Ft
Ludlow Series	Kirkby Moor Flags: grey-green flags with some gritty bands; much mica; some soft calcareous bands rich in fossils ..	1500
	Bannisdale Slates: leaden-grey sandy mudstones with thin bands of greenish sandstone and occasional grits; much jointed and cleaved; few fossils ..	5000
	Coniston Grits: fairly coarse grits with a band of flaggy mudstone ("sheer-bate flags") near middle; few fossils ..	4000
	Upper Coniston Flags or Coldwell Beds: olive-weathering grey flags with some grit; coarse grit at base with <i>Cardiola interrupta</i> ..	1500
	Lower Coniston or Brathay Flags: blue-grey laminated mudstone with gritty partings; have been used for roofing tiles and flagstones; fossils not abundant ..	1000
Wenlock Series	Stockdale Shales:	
	Browgill Beds: greenish shales with dark graptolitic shales and some greenish grit, 200 ft	
Llandovery Series	Skeigill Beds: black graptolitic shales with thin pale bands, 50 ft ..	250

The Stockdale Shales comprise thirteen zones—of which two refer to the Browgill Beds—characterized in most cases by different species of *Monograptus* but including some trilobites as zone fossils, such as *Encrinurus punctatus*, *Phacops glaber* and *Acidaspis erinaceus*.

In the Lower Coniston or Brathay Flags *Monograptus priodon*, *Cyrtograptus murchisoni* and *Retiolites geinitzianus* are the chief fossils.

Graptolites, usually of the *M. colonus* type, are more abundant in the Upper than in the Lower Coniston Flags. In addition to *Cardiola* (see Fig. 9) the basal bed often has swarms of *Dalmanites obtusicaudatus*. Fossils are rare in the Coniston Grits and the only form of note in the Bannisdale Slates is *Monograptus leintwardinensis*.

The fauna of the Kirkby Moor Flags is abundant and varied, especially in the calcareous bands which weather into a soft brown rock. One of the latter is a famous Starfish Band; others are rich in brachiopods such as *Rhynchonella* (*Camarotoechia*) *nucula*, *Chonetes striatellus* and *Dayia navicula*.

There are a few small inliers of Silurian rocks on the south side of the Cheviots; the best exposures are near the Border, though there are others on the south side of the Breamish Valley. Grits, greywackes and shales are represented, all steeply folded and much cleaved. They have yielded graptolites which prove them to be of Wenlock and Ludlow age like the inliers on the Scottish side of the Border.

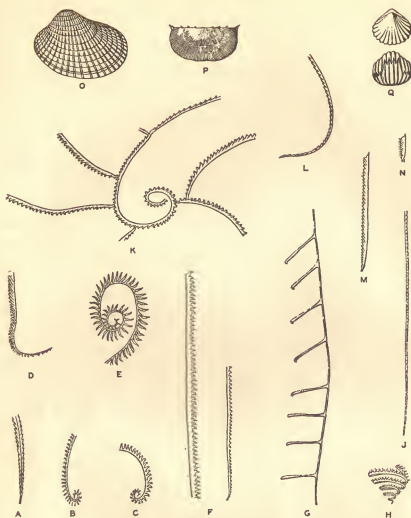


FIG. 9. Silurian Fossils (All natural size)

Lower Skelgill Beds.—A, *Akidograptus* [*Cephalograptus*] *acuminatus* (Nicholson). Middle Skelgill Beds.—B, *Monograptus triangulatus* (Harkness); C, *M. fimbriatus* (Nicholson); D, *M. argenteus* (Nicholson). Upper Skelgill Beds.—E, *M. convolutus* (Hisinger); F, *M. sedgwicki* (Portlock), distal and proximal portions; G, *Rastrites maximus* Carruthers. Browgill Beds.—H, *M. turriculatus* (Barrande); J, *M. griestoniensis* (Nicol). Lower Brathay Flags.—K, *Cyrtograptus munchisoni* Carruthers. Upper Coniston Flags.—L, *M. nilssoni* (Barrande). Bannisdale Slates.—M, *M. tumescens* Wood; N, *M. leintwardinensis* Lapworth. Coniston Grits.—O, *Cardiola interrupta* J. de C. Sowerby. Kirkby Moor Flags.—P, *Chonetes striatellus* Dalman; Q, *Rhynchonella* (*Camarotoechia*) *nucula* J. de C. Sowerby.

IV. OLD RED SANDSTONE SYSTEM

EARTH-MOVEMENTS

THERE ARE NO Downtonian rocks in Northern England. Whether they were ever laid down there, and later removed by denudation on the uplift of the district about mid-Palaeozoic times, we cannot say. We do know, however, that at some period after the deposition of the Kirkby Moor Flags the district was subjected to compressive forces from the south-south-east or north-north-west, which not only gave rise to broad folds that are responsible for the disposition of the major outcrops (*see* Fig. 2, p. 6) but impressed wrinkles or contortions on the strata, and also induced a re-arrangement of the particles of the less massive rocks so that they now have a slaty cleavage.

Great movements seldom take place all at once; they are usually preceded and followed by smaller disturbances, and so it was with these 'Caledonian' movements. The earlier movements were responsible for the unconformities we have noted in dealing with the Ordovician rocks, and some induced fold-axes along north-north-east lines.

In the Lake District the axes of the later or post-Silurian folding range east-north-east, and the most important upfold or anticline is that through Skiddaw. The present disposition of the outcrop of the Borrowdale Volcanic Series to the north and south of the main Skiddaw Slates outcrop is due to the erosion of part of the upfolded strata (*see* Fig. 2, p. 6). Some of this erosion took place during the Old Red Sandstone Period.

Folding was accompanied by faulting of various kinds, including over-thrusts.

Although in this district the record of the Old Red Sandstone Period is mainly one of alteration and denudation of pre-existing rocks, there was some formation of new ones. These fall into two classes: (a) igneous, and (b) sedimentary; and of these the former are the more important, for, apart from small patches of sandstones or marls in the Cheviots, the age of the only other sediments to be considered—mainly conglomerates—is somewhat doubtful. It will be discussed at a later stage when dealing with the Carboniferous.

IGNEOUS ROCKS OF THE CHEVIOTS

The igneous complex of the Cheviot Hills consists of the deeply dissected remains of a volcano intruded by granite and traversed by igneous dykes. Since it rests on upturned Silurian strata and, on the Scottish side of the Border, is transgressed by Upper Old Red Sandstone conglomerates wherein fragments of the lavas and granite abound, the age of the complex is regarded as Lower Old Red Sandstone. The first stages of vulcanicity were of explosive character and gave rise to the coarse ashes and agglomerates which rest upon folded and eroded Silurian rocks. This episode was quickly followed by an immense out-pouring of lavas which, even to-day after extensive



FIG. 10. *The igneous rocks of the Cheviots*
(Dykes are shown by heavy black lines)

denudation, cover an area of 230 square miles. Into this volcanic pile a large mass of granite was intruded, which now, after profound erosion, appears as a core of plutonic rock surrounded by the lavas and tuffs which dip gently away from it (see Fig. 10).

The concluding stages of this cycle of igneous activity were marked first by the intrusion of a series of dykes cutting both lavas and granite, and then by pneumatolytic alterations—especially tourmalinization.

Amongst the lavas there are rare deposits of red sandstone or marl. These, the only sedimentary rocks, are unfossiliferous; but they are thought to be of Lower Old Red Sandstone age.

There are surprisingly few exposures on the steep, rounded hills of the Cheviots, but conditions are better in the valleys, save where—as is often the case—the stream courses have been determined by crush lines. It is not easy, therefore, to make out a detailed sequence.

The Basal Agglomerate, 200 ft thick at most, is only known on the south side of the Cheviots, close to the Border. The included fragments—often large and even up to 5 ft across—are usually fine-grained mica-felsites or rhyolites; they resemble the rocks of certain flows in the succeeding group, though some are of a type not yet known *in situ*; others, smaller and near the base, are of Silurian shale.

Succeeding the Basal Agglomerate, and with a similar restricted distribution, is a suite of porphyritic rhyolites sometimes known as the Biotite Lavas or 'Mica-Felsites'. These are purple, brick-red or chocolate-coloured, and both feldspar and mica phenocrysts are prominent. The remaining lavas—the Pyroxene Andesites—make up the greater part of the Cheviot Massif. They are mainly purple or dark brown in colour except within a mile or so of the granite, where they are dark grey—a change possibly due to contact alteration. Although the vast majority are augite-hypersthene andesites, other types are known. These include glassy or pitchstone varieties near the Border to the west, and flows of trachy-andesite to the south-east; in the latter quarter beds of ash associated with the lavas attain their greatest development; elsewhere they are of less account but are not uncommon. The lavas are frequently scoriaceous and amygdaloidal, and the cavities are commonly filled with chalcedony.

The granite outcrop forms a roughly circular area some twenty square miles in extent in the centre of the lavas. The mass is believed to be not a plug but a laccolite. In places the lavas forming part of the original roof are to be seen. They are intensely metamorphosed, and the underlying granite also shows considerable variation due to assimilation of the country rock, which in one case has produced an augite-granite, whereas the normal rock is a pink granophyric rock, relatively poor in ferromagnesian minerals. There is a well-defined junction with the lavas on the south, but on the north granite and lavas are intricately interleaved. Here the granite is so basified by contamination that it is difficult, in the field, to distinguish the two rocks.

Aplitic veins traverse both the granite and the surrounding lavas, and in their turn are cut by dykes. The latter usually range either north-north-west or north-north-east (see Fig. 10), and are of four main types, of which a mica-porphyrite is the commonest, while the rest comprise augite-hypersthene porphyrites, quartz-porphyrites and felsites.

INTRUSIVE ROCKS OF THE LAKE DISTRICT

Probably no district in England of equal size can furnish such a variety of intrusive rocks as the Lake District. Many of them are acid in character, i.e. light-coloured igneous rocks, such as granites, containing much free quartz, but there are also examples of intermediate, basic and ultra-basic rocks; these differ from acid rocks in being, as a rule, darker in colour, and in possessing little or no free quartz but more of the ferromagnesian minerals—biotite, hornblende, augite or olivine. The intrusions also show considerable variations in form—stocks (large, steep-sided masses), bosses (irregular), laccolites (lenticular), dykes (wall-like) and sills (sheet-like) probably all being represented.



FIG. 11. Sketch-map showing the distribution of igneous intrusions in the Skiddaw Slates and Borrowdale Volcanic Series

Although confined to Ordovician rocks, most of these intrusions are believed to be of Old Red Sandstone age, though only in one case—that of Shap—can this be demonstrated. The more important of these intrusions will be dealt with in anti-clockwise sequence, according to their positions on the map (see Fig. 11).

Shap Granite.—The outcrop of this granite is about three square miles in extent and forms a rough oval extending east and west. According to Marr the intrusion forms a 'cedar-tree laccolith' in the Borrowdale Volcanic Series near the junction with the Coniston Limestone Series, and consists of a suite of porphyritic biotite granites with dioritic affinities. The content of accessory minerals is high, but special characteristics of this much-used ornamental stone are the large pink crystals of feldspar and the number of inclusions which usually show up as dark patches. These clots, known

as 'heathen', are frequently of basic character; many probably represent caught-up relics of an earlier intrusion, but some are partly assimilated fragments of Borrowdale or Conistone Limestone rocks. The 'Light' and 'Dark' Shap Granites of the building trade really grade into each other; they are believed to be due to the degree of pneumatolysis (the effects of heated vapours) on the plagioclase feldspars of the groundmass after consolidation, for the 'dark' variety occurs as ribs 2 ft to 15 ft wide on each side of the master joints, and the width of dark rock appears to depend on the size and persistence of a particular joint. The large pink crystals of orthoclase are apparently unaltered. This pneumatolysis is also responsible for the introduction of new minerals, especially molybdenite, in the country rocks.

The last stage of granite intrusion was followed by the injection of a series of radiating dykes of aplites, pegmatites, etc., some of which cut not only the granite and surrounding Borrowdale rocks, but also penetrate and metamorphose strata up to and including the Upper Ludlow.

While some hydrothermal action—introducing calcite, copper pyrites, zinc blende, haematite, fluorspar, and barytes, more or less in turn and accompanied in each case by quartz—may have taken place at a much later stage, it is clear, from the inclusions and the metamorphism, that intrusion was completed after Silurian times. It is also certain from fragments of the granite in the Carboniferous basal conglomerate, that intrusion was completed before the Carboniferous rocks were laid down. We must, therefore, refer this intrusion to the Devonian or Old Red Sandstone period.

Skiddaw Granite.—This granite has been intruded into the Skiddaw Slates near the major anticlinal axis of the Lake District (*see* p. 23 and Fig. 12.) There are three separate outcrops—in Sinen Gill, in the Caldew Valley and near the junction of the Caldew and Grainsgill. These are some distance apart, but the petrological similarity of the granites in these three areas and the great extent of the surrounding belt of Skiddaw Slates affected by heat clearly indicate the presence of a continuous granitic mass at shallow depth. The rock is medium-grained, light-grey in colour and usually made up of orthoclase, oligoclase, quartz and black mica, though some muscovite occurs also.

The thermally altered slates show an outermost zone of soft slate with chialstolite (a variety of andalusite) and spots representing incipient crystals of cordierite; within this is a well-hardened belt that passes, with increasing recrystallization, into a central zone of very hard, crystalline rock known as andalusite-cordierite-biotite hornfels. The alteration also affects adjacent parts of the Carrock Fell igneous complex.

In the Grainsgill area hot gases and solutions driven off during consolidation of the granite altered much of it to greisen, modified large areas of hornfelsed slate and formed quartz veins that bear the tungsten ores, wolfram and scheelite.

Carrock Fell Complex.—Almost immediately to the north of the Skiddaw Granite is the plutonic complex of Carrock Fell. It forms a stock-like mass, a mile broad by four miles long, roughly parallel to the grain of the country rock. The latter is mainly of highly inclined Borrowdale Volcanic Series, but Skiddaw Slates come in on the south, and Drygill Shales to the north. The

northern and eastern boundaries of the intrusion, and possibly the southern margin also, are defined by faults, but normal junctions obtain on the west.

The complex includes basic and acid rocks. As a result of the recent resurvey, it is now considered that the basic suite of gabbros on the south side of Carrock Fell were intruded in order of decreasing basicity, and were followed by the 'hybrid' diabase north of the summit ridge. The acid

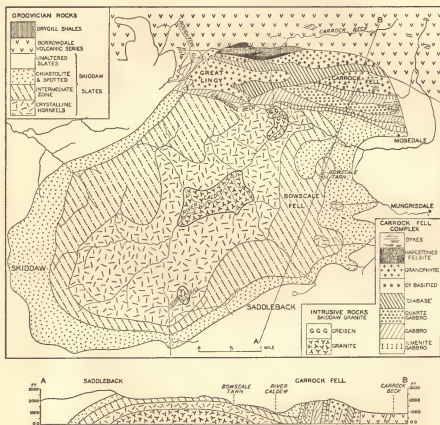


FIG. 12. Sketch-map of the Carrock Fell Complex and the Skiddaw Granite with its metamorphic aureole

rocks, principally granophyres, are, as a whole, later; these also came up as a series of distinct injections, the basified granophyres south of Carrock Fell summit being followed by the normal granophyres of Carrock Fell and Great Lingy, and the Harestones Felsite.

The distinct types of gabbro and granophyre in the main mass of Carrock Fell all have lenticular outcrops parallel to the length of the intrusion.

In the gabbros the chief minerals are plagioclase feldspars—usually near labradorite—and augite. Varieties with free quartz and up to 59½ per cent. of silica are to be found in the central part of the eastern area, and belts of basic rocks rich in ilmenite and magnetite, with a silica percentage as low as 33½,

characterize the northern and southern portions. These varieties frequently grade into each other, but in some cases the planes of junction are abrupt, dip at high angles to the south and are parallel to the banding and foliation that is widespread in the gabbro. Some are separated by screens of Borrowdale lava.

The diabase resembles the gabbro mineralogically, but is usually finer grained than that rock.

The granophyres are pink to grey rocks of rather fine grain, made up of quartz and feldspar largely in micrographic intergrowth; augite appears to be the only ferromagnesian mineral. Veins of granophyre penetrate gabbro, but have not been noticed in the diabase against which the granophyre locally develops a chilled edge.

There is usually a rapid passage from granophyre to gabbro through intermediate mixed or hybrid types that were probably formed *in situ*; but within the main mass of granophyre there are also certain basic granophyric types that possibly originated as hybrids at depth.

Precise evidence of the age of this complex is lacking; it is definitely newer than the Borrowdale Volcanic Series, and is probably later than the main folding, but appears to be older than the Skiddaw Granite and the thrusting that affects the Skiddaw Slates to the west. On structural grounds, therefore, it appears to be of Old Red Sandstone age; and similar arguments may be applied in the case of the Skiddaw and Eskdale granites and the Ennerdale Granophyre.

Ennerdale Granophyre.—Much of the ground between Buttermere, Ennerdale and Wastwater is occupied by this granophyre. The intrusion is essentially a simple stock-like mass invading the Skiddaw Slates and Borrowdale Volcanic Series; its markedly irregular outline is due to deep dissection by the Ennerdale and Buttermere valleys, and to the preservation of portions of the original roof.

The normal rock is a pinkish, rather fine-grained mixture of quartz and feldspar—often in micrographic intergrowth—with scattered patches of a greenish, chloritized, ferromagnesian mineral. There are, however, many variations from this type and some, which are dark grey in colour and distinctly basic, represent, in part, an earlier consolidation; although frequently completely surrounded by normal granophyre, they are intimately associated with mixed or hybrid types that were probably intruded as such.

A later, more acid, phase of intrusion is represented by a few rhyolitic, aplitic and felsitic dykes which traverse the main intrusion.

The alteration of the adjacent rocks is nowhere very intense, but hornfelsed and spotted rocks are developed at considerable distances from the outcrop of the granophyre.

Eskdale Granite.—This intrusion, the largest in the Lake District and one of the most accessible for exploitation, has been but little quarried, save for roadstone at Beckfoot in Eskdale, and at Waberthwaite. There are two outcrops (see Fig. 11, p. 26), of which the larger, twelve by four miles in extent, ranges from the foot of Wastwater across Eskdale and Miterdale to Bootle, while the smaller, covering an area of about one and half square miles, is confined to the head of Wasdale.

The commonest rock-type is a coarse perthitic granite with much free quartz, muscovite and a little biotite; it is pink or light greyish-green in colour, but is frequently stained red with haematite. Fine-grained or porphyritic types of more acid character are also present, especially near the margin of the intrusion near Ravenglass, Devoke Water and Waberthwaite; a grey biotite-rich granite is developed throughout the southern part of the outcrop.

The country rock belongs mainly to the Borrowdale Volcanic Series, but certain hornfelsed sediments in contact with the granite in the Ravenglass area are altered Skiddaw Slates. At the foot of Wastwater the granite outcrop approaches that of the Ennerdale Granophyre, but actual contacts are not visible. Although claimed by some authors, including Dwerryhouse, to be a laccolite, the general shape of this intrusion conforms more to that of a stock.

In common with others in the district, this intrusion is considered to be of Old Red Sandstone age, but the only definite evidence is that the granite has metamorphosed Borrowdale rocks and appears to be considerably older than the Triassic sediments which abut against it on the west.

Other Intrusions.—Space does not permit of the description of many other intrusions in the Lake District (*see* Fig. 11, p. 26), but attention may be drawn to the Threlkeld Microgranite, which has been intruded between the Skiddaw Slates and rocks of the Borrowdale Volcanic Series. Although the mass is of considerable extent the amount of metamorphism is negligible, and graptolites have been found within 18 in. of the contact. There is also the so-called "Embleton Granite" in the Skiddaw Slates between Bassenthwaite and Cockermouth; this is a quartz-mica-diorite with strong affinities to the granophyres. Dolerite occurs at Castle Head—which has been claimed to be a volcanic neck—and at Friars Crag, Keswick; while the minette of Sale Fell, Wythop, the picrite at Dash near Skiddaw, and the beautiful rock of the Armboth Dyke in the Thirlmere area are worthy of mention. Farther east there is a gabbro at Haweswater and a microgranite at Dufton Fell.

INTRUSIVE ROCKS IN THE MANX SLATES

The rocks included under this heading are confined to the Manx Slates into which they were intruded before Carboniferous times. Dykes of Carboniferous and Tertiary age are dealt with elsewhere.

There are two major intrusions of granite in the island—at Dhoon and at Foxdale—cropping out along the central stratigraphical axis of the Manx Slates; they differ considerably in mineralogical composition and in mode of occurrence. That of Dhoon is a porphyritic microgranite and appears to form a rude column with steep walls—a stock—whereas the Foxdale mass, which is a coarse grey muscovite granite, shelves gradually beneath the slates and is possibly a laccolite.

Two smaller plutonic intrusions may be mentioned. That near Oatland consists of gabbroid rocks pierced by a granite of Dhoon type which has assimilated some of the basic rocks invaded; that of Ballabunt is a quartz diorite.

Minor intrusions of pre-Carboniferous age are represented by two series of dykes differing in composition but possessing a uniform north-east to south-west trend along the strike of the Manx Slates. One series, the earlier, consists

of microgranites and felsites (elvans) and is definitely related to the granites, being restricted to narrow belts on their flanks. The greenstone dykes, chiefly dolerites and minettes, that characterize the other series, are more numerous and widespread; they have no obvious connexion with the granites.

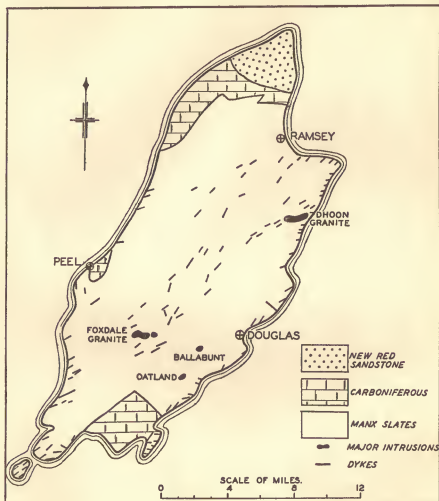


FIG. 13. Sketch-map showing the distribution of the pre-Carboniferous intrusions of the Isle of Man

The Manx Slates were folded and crushed previous to the intrusion of granite and of both series of dykes. It is equally clear, however, that they subsequently suffered further lateral compression, for the Dhoon Granite in particular has undergone considerable shearing movement along its margin, and in most cases the dykes have been torn, crushed and dragged out into disconnected lenticular masses.

V. CARBONIFEROUS SYSTEM

INTRODUCTION

THE CARBONIFEROUS ROCKS of England and Wales are usually divided, from below upwards, into three lithological groups, namely the Carboniferous Limestone Series, the Millstone Grit and the Coal Measures. This subdivision is not everywhere satisfactory, however, because of lateral changes in the character of the rocks. For example, in Lancashire south of the area dealt with in this account, the greater part of the Carboniferous Limestone Series is represented by marine shales with subordinate thin limestones. This type of deposit, known as the 'basin facies', changes in a northerly direction, at about the latitude of Lancaster, into a 'limestone facies' consisting of massive limestones; and this facies characterizes a belt of country that includes the Kendal-Ravenstonedale area, Furness and West Cumberland. To the north-east, however, another change sets in. First the upper part of the Limestone Series splits into the individual limestones, separated by shales and sandstones, that constitute the Yoredale facies. A change then affects the lower part of the formation, and these measures, as the Border is approached, lose their marine limestones almost entirely and consist largely of sandstones and coal-bearing shales, so that in Northumberland the name 'Carboniferous Limestone' for the Series is somewhat of a misnomer.

In the Millstone Grit the changes that take place are for the most part as between more shaly and more sandy beds, so that the development of sandstone from which the formation derives its name is not everywhere within the same stratigraphical range. Moreover, the thickness of the Millstone Grit in the Northern England region is, at its maximum, but one-tenth of that in Lancashire. The Lower and Middle Coal Measures, also, are much thinner than in Lancashire, but it is obvious that the causes responsible for the changes in the Lower Carboniferous rocks had almost, if not entirely, ceased to operate in Upper Coal Measures times. These lateral variations in the rocks were due to changes in distribution of land and water, in depth of water, and to the influence of the rivers bringing in sediments caused by uneven but usually downward movement of the sea bottom. Estuarine or deltaic conditions predominated almost throughout Carboniferous times in Northumberland, while in Lancashire these conditions did not obtain until Millstone Grit times. During the early part of the Carboniferous a peninsula extended from Durham to the Isle of Man, but later this was submerged.

The transgression of the Carboniferous rocks across pre-existing formations is one of the major features in the geological history of Northern England. In the Isle of Man (see Fig. 13) they rest on the Manx Slates, in the Lake District, and to a less extent in Durham also, on various members of the Ordovician and Silurian systems from the Skiddaw Slates to the Kirkby Moor Flags, and in the Cheviot area on Silurian strata and Old Red Sandstone lavas. The basal rocks of different areas, even when they are conglomerates of similar appearance, are not of one age, and thousands

of feet of rocks had accumulated in the northern and southern portions of the region before sedimentation set in over what is now the Lake District and the Alston area. Moreover, there are considerable internal changes in the sediments themselves; massive limestones of one area become divided by thick masses of shales and sandstones as they are traced into another area, and marine sediments give place to rocks accumulated in lagoons or deltas.

Viewing the region broadly, we may say that south of the latitude of Penrith (Fig. 14) limestone predominates in the lower part of the Carboniferous Limestone Series, such shales and sandstones as occur being comparatively thin, whereas in the upper part of the series the reverse obtains. On the other hand, north of an east and west line through Penrith, limestones, though persistent for miles, are subordinate to shales and sandstones throughout the formation; there is also proportionally more limestone in the west than in the east and north-east. From the prevalence or comparative absence of limestone at one or more localities we cannot infer contemporaneity, for it is certain that in different areas beds occupying similar positions in the local successions may differ considerably in age; thus the lowest limestone of Shap is considerably older than the lowest limestone—the Seventh—of West Cumberland. The key to the relative ages of the different limestones is supplied by various zone-fossils or suites of fossils. It has been proved that deposition commenced much earlier south-east of a line joining Penrith and the Duddon estuary than elsewhere around the Lake District, but not earlier than in north-east Cumberland and Northumberland, where the rocks, however, are of different types.

For rocks accumulated under such diverse conditions as obtained during the earlier part of the Carboniferous Period it is obvious that no detailed lithological sequence can be everywhere applicable. A description will therefore be given first of the basal conglomerates, though these may be of various ages, and then of the finer-grained strata, commencing with those of Northumberland.

BASEMENT CONGLOMERATES

At many places in the north of England a conglomerate is present beneath rocks generally admitted to be of Carboniferous age. Within our region of Northern England the most important are those which partly rim the Lake District and those along the Pennines.

The conglomerate west of Penrith is usually known as the Mell Fell Conglomerate, from the place near Ullswater where it attains greatest prominence. Here it consists of some hundreds of feet of reddish pebbly rocks; it thins rapidly but unevenly as it is traced round the northern rim of the Lake District until it disappears at Cockermouth; in a southerly direction it persists beyond Shap; there are patches of it near Kendal and still farther southward in Cumberland and Furness on both sides of the Duddon Estuary.

This rock presents several anomalies; for instance, in the Mell Fell area it includes, in addition to material from the grits and slates of the Slate Series, some Coniston Limestone and many large angular fragments of the Coniston

Grit which do not appear to have travelled far, yet no outcrops of them are known in this region; on the other hand Borrowdale rocks, which crop out in the vicinity, are locally extremely rare or even absent as pebbles. Theories of origin have varied from ice-action proposed by Ramsay, and coastwise drift advocated by Clifton Ward, to the more acceptable suggestion of R. D. Oldham of a torrential fan deposit. J. F. N. Green has suggested that there may have been a continuation of the pre-Bala unconformity of

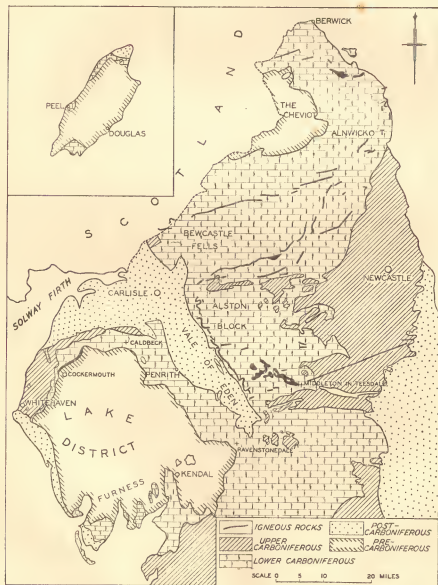


FIG. 14. Sketch-map showing distribution of the Carboniferous and associated igneous rocks in Northern England

the southern Lake District into this area, so as to bring Coniston Limestone and Silurian Beds across the present outcrop of the Borrowdale Volcanic Series on to the Skiddaw Slates west of Mell Fell at a small vertical distance above the surface of to-day. Although we regard the Watch Hill Grit as part of the Skiddaw Slates and not basal and transgressive Bala Beds, as did Mr. Green, the existence of Bala rocks at Drygill favours this suggested explanation of the paucity of Borrowdale debris and the predominance of Silurian grits in the conglomerate at Mell Fell.

In the Pennine region there are frequently two, and in places three, conglomerates. The uppermost one, usually grey in colour, has many quartz pebbles, and is associated with argillaceous and calcareous material that links it to the limestones above. The one at the bottom, sometimes known as the Polygenetic Conglomerate, contains pebbles strange to Cumberland; some may have been derived from Scotland; others resemble Cheviot rocks. The other conglomerate that in places intervenes is, like the bottom one, deep red in colour; it carries many pebbles of vein quartz but few strange pebbles; together with the intercalated sandstones and shales it constitutes the Roman Fell Beds.

These red conglomerates of the Pennines and the Lake District have been claimed as Old Red Sandstone deposits, though one at Ravenstonedale is believed to lie above the Pinskey Gill Beds which occur at the base of the Carboniferous. Definite evidence of age is lacking; the red coloration is indicative of conditions of formation rather than of age; and some of the beds may be regarded, as in North Wales, as the early Carboniferous disposal of rock waste accumulated to a large extent during the Devonian Period.

Of the more distant occurrences of conglomeratic beds mention may be made here of the Roddam Dene Conglomerate of Northumberland, and the conglomerates and the Peel Sandstone of the Isle of Man, though the latter are dealt with elsewhere (*see* p. 42). The Roddam Dene Conglomerate consists of well-rounded pebbles, almost all of Cheviot andesites up to 6 inches across, set in a matrix of greenish-grey mudstone. Although only seen in a few ravines, being mainly masked by thick glacial deposits, it must occupy several square miles of the eastern flank of the Cheviots and, in places, must be 200 to 300 ft thick. Some intercalated bands of red and green sandstone are present, but the precise relationship of these and the conglomerate to the Carboniferous strata and Cheviot volcanic rocks is not known. The deposit has been mapped as basal Carboniferous, but, either as a whole or in part, could range from Upper Old Red Sandstone to Cementstone Group in age.

CARBONIFEROUS LIMESTONE SERIES

Northumberland and North-East Cumberland.—The classification of the Lower Carboniferous rocks devised for Northumberland holds good, with certain modifications, for North-East Cumberland, and is as follows:

	<i>Northumberland</i>	<i>North-East Cumberland</i>
Bernician	Limestone Group	Limestone Group
	Scremerston Coal Group	Birdoswald Limestone Group
Tuedian	Fell Sandstone Group	Craighill Sandstone Group
	Cementstone Group	Fell Sandstone Group
		Cementstone Group

Cementstone Group.—Although sandstones are common, especially towards the base and the top of the group, the leading feature is a long series of grey or reddish-grey shales with innumerable thin bands of 'cementstone'. In the Cheviot area these are compact, impure limestones of freshwater or estuarine origin.

On the south side of the Cheviots the group is relatively thin, but increases northwards to perhaps 3000 ft in the Tweed Valley, and probably to a like amount along the Border to the south-west. In the valley of the Tweed a volcanic series—of olivine-basalts known as the Kelso Traps—occurs at the base, and is followed by the Carham Limestone, a remarkable deposit, unfossiliferous, dolomitic, and much broken by contemporaneous brecciation, thought to have been laid down in concentrating waters. East of the Cheviots the Roddam Dene Conglomerate is regarded as forming the local base of the group.

In Northumberland the chief fossils are *Spirorbis*, *Naiadites*, ostracods, fish-scales and plant-debris in which Scottish 'Oil Shale Group' forms can occasionally be identified. The uppermost beds contain occasional rhynchonellids, and, more rarely, crinoid debris, but the most important band is one containing the algae *Garwoodia* [*Micheldeania*] and *Ortonella*.

The same algae also occur in north-east Cumberland, but here the rocks are definitely marine for the most part and include such brachiopods as *Productus*, *Syringothyris cuspidata* and *Athyris glabristria*, which belong to the C₁ Subzone of the coral-brachiopod zonal scheme utilized for dividing the Lower Carboniferous; thus correlation is permitted with other areas.

Fell Sandstone Group.—This group of pink, coarse, false-bedded and massive sandstones, from 600 to 1000 ft in thickness, gives rise to bold escarpments across many miles of country round the Cheviots and along the hills of the Border country. The rocks are generally too coarse and soft for building purposes, but some of finer-grained material yield a freestone of high quality, as, for example, at Doddington Quarries north-east of Wooler.

Fossils are rare and usually consist of plant debris, seldom identifiable even generically, but in Cumberland the shales between the massive sandstones frequently contain thin limestones with marine fossils.

Scremerston Coal Group and its equivalents.—Though well defined, and almost wholly of estuarine or freshwater character in Northumberland, the Scremerston Coal Group undergoes much change towards the south-west (see Fig. 15, p. 38).

Typical Scremerston strata exhibit a recurrence of Cementstone conditions—shales with bands of impure limestone—but accompanied in this case by coal seams. At Berwick the group attains a thickness of 1000 ft and has at least ten workable coals (some over 6 ft thick). At Alnwick the thickness has dwindled to 300 ft and there are only four thin seams; farther west, there is a rapid increase in thickness to cover 3000 ft, but the coal seams are of no great value. In general the coals, though easily worked, are of poor quality, soft and with many 'dirt' or shale partings. The Main and the Cooper Eye



A.—SYNCLINE IN MIDDLE LIMESTONE GROUP, GREEN'S HAVEN, BERWICK-ON-TWEED



B.—WHIN SILL ON SANDSTONE, CASTLE POINT, EMBLETON, NORTHUMBERLAND



FOSSIL PLANTS TYPICAL OF THE COAL MEASURES

(A-D, F, half natural size; E, natural size)

Productive Measures (Yorkian).—A, *Neuropteris heterophylla* Brongn.; B, *Mariopteris muricata* (Schloth.); C, *Alethopteris lonchitica* (Schloth.).

Barren Red Measures: Whitehaven Sandstone (Staffordian).—D, *Sphenophyllum emarginatum* Brongn.; E, *Linopteris muensteri* Eichw. Jockie's Sike (Radstockian).—F, *Alethopteris serli* Brongniart.

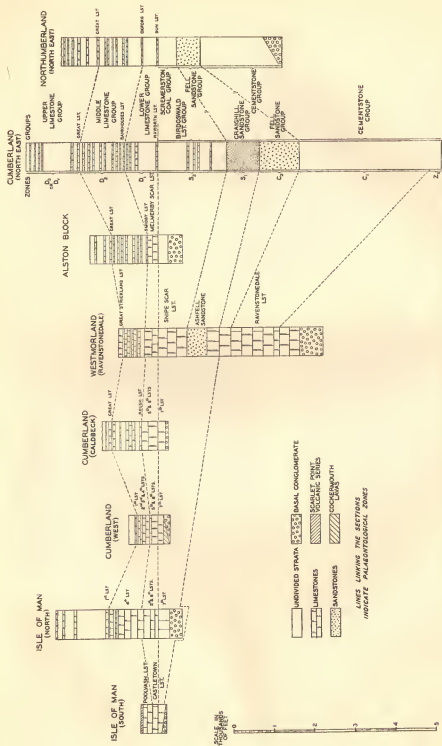
seams in the type area—east and north of the Cheviots—are the best coals in this group. In the Redesdale and North Tyne valleys, the Plashetts Coal, a 6-ft seam, is the best in thickness and quality.

The changes in lithology in a south-westerly direction begin with the appearance of marine limestones—first the limestones of the N. Tyne in the upper part of the group and then others at lower levels. As the Pennines are approached the changes become more marked, and in North-East Cumberland it would be misleading to refer to this belt of strata as the Scremerston Coal Group. There the lower portion, some 700 ft in thickness, consists mainly of sandstones resembling those of the Fell Sandstone Group below, but separated from it by strata containing four thin limestones (the Kingwater Limestones) that yield a marine fauna indicative of a horizon in the S_1 Subzone. To this group the name Craighill Sandstone has been given. It is succeeded by the Birdoswald Limestone Group, in which, while sandstones are still abundant, limestones are common, and the strata exhibit the typical Yoredale 'rhythm', i.e. a manifold repetition of the sequence: limestone, shale, sandstone, frequently topped by a thin coal seam. Fossils, which include the well-known basaltiform coral *Nemato-phyllum minus*, indicate that the Birdoswald Limestone Group belongs to the S_2 Subzone.

Up to this point we have been dealing only with the northern part of our region. The rocks described do not occur to the south, where they are either absent entirely or represented by totally different rocks, but the entry of the coral *Nemato-phyllum minus*, and the brachiopods which accompany it, provides an important datum for correlation purposes, since the limestones in which it occurs spread over the whole district.

Limestone Group.—Sandstones and shales still predominate, but limestones now occur at intervals of 100 ft or so and reach thicknesses of 50 or 60 ft, and many of them are present over hundreds of square miles of country in Northumberland, Durham and North-East Cumberland. Since they are the repository of ores of lead and associated minerals, particularly in Durham, these strata are well known, and both limestones and sandstones have received local names. Many of the limestones overlie coals, some of which such as the Shilbottle Seam beneath the Acre or Six Yard Limestone, and the Little Limestone Coal, are of considerable importance, though others are of value but locally.

The Limestone Group is subdivided into Lower, Middle and Upper groups (see Fig. 15, p. 38) which have their own lithological and palaeontological characteristics, although special features are frequently restricted to individual limestones. The Watchlaw Limestone, for instance, in the Lower Group, is usually a pale pseudo-brecciated rock, whereas the Oxford (=Bank-houses or Smiddy) Limestone at the base of the Middle Group is dark and contains nodules of the alga *Girvanella*; with the Acre Limestone again, somewhat higher in the sequence, there is associated a coral fauna peculiar to this horizon, of *Cyathaxonia*, *Caninia* and Zaphrentids, that affords the principal link with the Scottish sequence at Dunbar.



The Great Limestone at the base of the Upper Group is the highest of the thick limestones and is extraordinarily persistent both in lithology and fauna throughout the north of England, for it is the Main Limestone of the Yorkshire Dales and the First Limestone of West Cumberland.

The goniatite *Anthracoceras* cf. *discooides* from the Thornbrough Limestone and the nautiloid *Tylonautilus nodiferus* from the Styford Shales, near the top of the Upper Limestone Group, are valuable index fossils. There are many other fossils, and in terms of Vaughan's zonal sequence the Lower Limestone Group is referred to D_1 , the Middle Group to D_2 , and the Upper to D_3 or D_7 .

Shap-Ravenstonedale.—To the south of Penrith the zonal sequence worked out by E. J. Garwood has made the Shap-Ravenstonedale area, where several thousands of feet of predominantly calcareous rocks are preserved, the type region for marine Lower Carboniferous in the north of England. Here the oldest Carboniferous rocks appear to be the dolomites and shales of Pinskey Gill in Ravenstonedale, which are believed to occur beneath the 'basal' conglomerate. In addition to *Spirifer* and *Lingula* they contain the teeth of the fish *Psephodus*. These beds, however, have not been found elsewhere, and as a rule the lowest calcareous rocks are limestones that appear to have been converted into dolomite soon after deposition. They are characterized by bands containing algae such as *Solenopora* and *Ortonella*, but the brachiopod *Athyris glabristria* is the zonal fossil. Near the top of that subzone (C_2) the limestones are frequently oolitic and, in places, conglomeratic—as in the case of the Brownber Pebble Bed, which contains pebbles of quartz set in a matrix of calcareous grit or oolite carrying *Syringothyris cuspidata*. Around Kendal there is some calcareous grit but without pebbles; farther south the bed appears to be absent. Next come calcareous mudstones containing the coral *Michelinia grandis* and so corresponding to the upper part of the C_2 Subzone.

Hitherto we have been dealing with limestones of restricted extent deposited in arms of the sea or in lagoons, but the appearance of the *Lithostrotion* corals in the succeeding *Productus corrugatohemisphericus* Zone (S) marks a widespread submergence which was accompanied by the deposition of limestones, not only here but throughout our region. Shallow-water limestones, known as the Gastropod Beds (S_1) are typical of the lower part of this zone; *Davidsonina* [*Cyrtina*] *carbonaria* (S_2) is characteristic of the middle of the zone, while in the upper part the most important fossil is the basaltiform coral *Nematophyllum minus* (S_3) which is commonly followed or accompanied by crowds of bryozoa and occasionally by an abundance of crinoids.

Sandstones call for little comment. That on Ashfell Edge is the only one of importance (see Fig. 15, p. 38); near Shap it closely follows the beds with *Michelinia*, but in Ravenstonedale lies at a higher horizon. Fossils are few in the sandstone except near the top, and as the rock transgresses certain horizons, faunas peculiar to them disappear locally. The rock is of further interest in that it probably represents in an attenuated form the important Fell Sandstone Group of the country farther north (p. 36).

Limestones which are spotted, or are pseudo-brecciated—possibly as a result of shrinkage during initial drying—occur above the Bryozoa Band. Corals such as *Dibunophyllum* and *Lonsdaleia* appear and characterize certain horizons; but a bed with *Girvanella* is again used for dividing the lower part (with *Palaeosmilia munchisoni* subzone D₁) from the upper part (with *Lonsdaleia floriformis* and *Dibunophyllum muirheadi* subzones D₂ and D₃) of the *Dibunophyllum* Zone. Particular horizons or bands are frequently marked by brachiopods such as *Daviesiella comoides*, by foraminifera such as *Saccamminopsis* or by the peculiar compound coral *Orionastraea*.

West Cumberland.—In West Cumberland the Lower Carboniferous falls into two subdivisions: (1) a lower group, about 700 ft thick consisting mainly of limestones which are named from the top downwards First to Seventh Limestone, and (2) a series of shales, sandstones and grits with subsidiary thin and inconstant limestones forming the Hensingham Group that varies in thickness from 100 ft to over 1600 ft. In a north-easterly direction some of the limestones of the lower or main group split and become more widely separated until finally, in North-East Cumberland (see p. 37 and Fig. 15), the strata consist of a series of shales and sandstones with comparatively thin but constant beds of limestone. In the same direction the Hensingham Group begins to reflect more settled conditions of sedimentation, the individual beds become more persistent until ultimately the group merges into the Upper Limestone Group of North-East Cumberland and Northumberland (p. 37).

Throughout West Cumberland the lowest beds of limestone are approximately of the same age (S₂), but for a distance of about six miles north-east of Cockermouth thick flows of olivine-basalt (p. 52) lie between the bottom limestone and the basal conglomerate.

The lower group, consisting mainly of limestone, is the chief repository of haematite which replaces the rocks metasomatically, giving a perfect passage from limestone to iron-ore. In spite of the predominance of limestone it is evident that the waters were shallow, and contemporary potholes and channelling show that the rocks nearly reached the surface or actually emerged from the sea more than once.

The lowest or Seventh Limestone is characterized by *Nematophyllum minus*, while bryozoa and crinoids are locally abundant. In the Sixth Limestone the stout *Lithostrotion martini* is common, and in the Fifth Limestone masses of *Lonsdaleia* and scattered corals, such as *Palaeosmilia munchisoni*, occur. Some 60 ft or so above the bottom of the Fourth Limestone *Girvanella*, at the base of the D₂ subzone, forms small rusty nodules, while higher beds are crowded with the foraminifer *Saccamminopsis* or have masses of *Lithostrotion junceum*. The First or Great Limestone has *Lonsdaleia floriformis* and *Dibunophyllum muirheadi*. Some of the brachiopods are also characteristic, especially *Chonetes hardrensis* in the shale between the Fifth and Sixth Limestones. In the Hensingham Group brachiopods are abundant, particularly *Schellwienella*, but the most important fossils are the cephalopods *Tylonautilus nodiferus* and *Anthracoceras glabrum*.

Furness and South Cumberland.—The Carboniferous rocks of this region bear more resemblance to those of Shap and Ravenstonedale than to those of West Cumberland. They begin with the Basement Beds, 300 to 800 ft thick, of shale, conglomerate, sandstone and limestone, followed by the main mass of limestone which is divided into five groups. At the base is the Martin Limestone, 150 to 450 ft thick and of C_1 – C_2 age, which consists of calcite-mudstone and tough grey limestone, and ends with the 2- to 4-ft Algal Band of limestone. Next comes the generally massive light grey Red Hill Oolite, 170 to 200 ft thick of C_2 age, followed by the Dalton Beds—grey and dark grey limestones in thin posts, 380 to 850 ft thick, ranging in age from C_2 to S_1 . The succeeding Park Limestone (S_2) consists of 400 to 450 ft of white or cream massive limestone which is not “grieked”, whereas the next or Urswick Limestone, 375 to 400 ft thick, is particularly liable to that form of weathering. This is white or cream well-bedded limestone with a definite shale bed—the Woodbine Shale—about a third of the way up.

The succeeding Gleaston or Yoredale Group (D_2 – D_3) begins with the *Girvanella* Band, 3 ft of dark limestone, followed by black shales up to 1400 ft thick; these in their lower 500 ft contain thin dark cherty or coarse crinoidal limestones and thin sandstones.

Isle of Man.—In the Isle of Man rocks usually referred to the Lower Carboniferous occur in three areas: (1) around Castletown, where they consist of basal conglomerate, limestones and volcanic rocks (p. 52); (2) deeply buried under Glacial drift at the north end of the island, but penetrated by several borings giving a succession of (a) basement beds, (b) limestones, (c) shales with limestones; (3) on the west coast as the Peel Sandstones, the age of which is not certain.

At the south end of the island 300 to 400 ft of the dark thin-bedded Castle-town Limestone succeeds about 60 ft of basal conglomerate, and is followed by about 200 ft of the Poolvash Limestone. This is mostly pale except for the upper 30 to 50 ft that forms the Black Marble on which rest the volcanic rocks. *Goniatites* as well as the usual brachiopods and corals occur in this series, and the Black Limestone is further characterized by an abundance of *Posidonia*; so that we are able to link the sequence with the basin facies of Lancashire and farther south-east as well as with the northern limestone facies (see Fig. 15, p. 38).

At the north end of the island the sequence commences at a later date and is of different character from that in the south. Conglomerates occur not only at the base—where they are recorded as up to 100 ft thick—but are also interdigitated with the main group of limestones, and even occur in the higher shales with limestones. The main group of limestones, amounting to about 800 ft, appears to be equivalent to that making up the First to the Seventh in West Cumberland, whereas the higher beds, of which some 500 ft are known, are more like the Upper Limestone Group of North-East Cumberland than the Hensingham Group of West Cumberland. No volcanic rocks are known here, but the reddening of some of the upper sediments may be due to washing of volcanic detritus.

The Peel Sandstones consist of red and mottled sandstones with beds of conglomerate and some lenses of impure limestone. Various ages from Ordovician to Permian have been suggested for this formation, but it is probably equivalent to that of the basal conglomerate of the Carboniferous in the other two Manx areas, though it should be borne in mind that these conglomerates do not mark a specific horizon. Such fossils as occur are mainly derived, strangely enough, from a Salopian type of Wenlock, although others appear to have come from a deposit of Keisley Limestone, neither of which is known *in situ* on the island.

MILLSTONE GRIT

In the area here described as Northern England there is little which is strictly comparable lithologically with the Millstone Grit Series of Lancashire, Yorkshire and Derbyshire. It is true that there are sandstones—some of them gritty—between the chief coal-bearing measures and the principal limestones, but similar rocks are to be found at much higher and lower horizons. With the progress of palaeontological and stratigraphical research many of the older conceptions of the Millstone Grit Series have had to be revised, and in many areas, in addition to parts of our own, strata previously regarded as Millstone Grit have been relegated to the Carboniferous Limestone Series. The researches of Bisat have shown that Carboniferous rocks may be zoned by means of goniatites, and these zones, where they are well developed, give a much more reliable sequence and time scale than lithology alone. Unanimity has not yet been reached, however, as to which zones shall be comprised in the Millstone Grit Series.

Much of the Hensingham and Upper Limestone Groups, in spite of their affinities to the Carboniferous Limestone Series, fall into the Upper *Eumorphoceras* Zone which in Lancashire and Yorkshire is included in the Millstone Grit Series; it must be pointed out, however, that the identification of that zone in our region appears to depend on the presence of *Anthracoceras* and *Tylonautilus nodiferus*, both of which are extremely rare.

No reliable evidence of the presence of the two middle major zones, *Homoceras* (H) below, and *Reticuloceras* (R) above, has yet been found in Northern England, but in West Cumberland the existence of the topmost subzone (*Gastrioceras cumbriense*) of the Millstone Grit is undoubted; it comprises the strata overlying the Udale Coal. The apparent absence of zones H and R implies a non-sequence unless it be assumed that during mid-Carboniferous times deposition was taking place in two separate basins as follows: (1) in the southern Pennines, which possibly included the south end of the Isle of Man, sedimentation continued unbroken—at first in the sea and later in deltas subject to periodic incursions of a sea in which the goniatites that now characterize the various horizons were being evolved; (2) in the northern basin the Lower Carboniferous types of rocks continued to be laid down, but included more sandy and muddy detritus as time went on. In the west corals were largely replaced by brachiopods, but goniatites did not flourish until late in Millstone Grit times, Palaeontological evidence from the east is at present too scanty to be of value.

In Northumberland and Durham the Millstone Grit is frequently defined as comprising the measures lying between the lowest coal of the Coal Measures

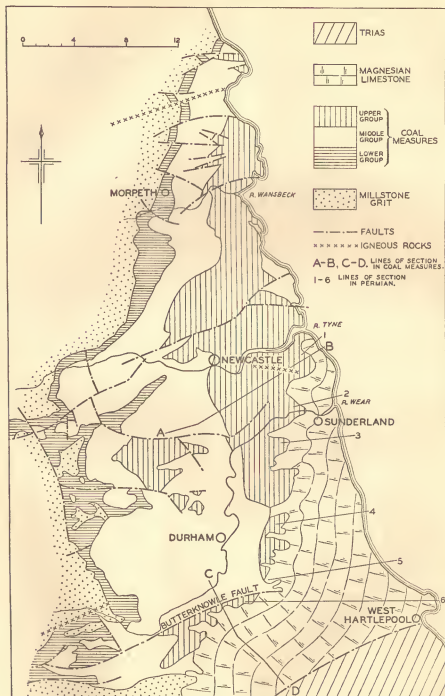


FIG. 16. Sketch-map of the Northumberland and Durham Coalfield

(Note: the lines of sections A-B and C-D refer to Fig. 17; those of sections 1 to 6 to Fig. 23)

and the highest limestone. Three grits are known in Durham, parted by considerable masses of shales and clays with occasional thin coals, the whole amounting to about 300 ft. In Northumberland the supposedly equivalent measures are 600 ft thick and include less shale. Several species of plants have been found; these include *Neuropteris schlehani* and *Lyginopteris hoeninghausi*, also *Alethopteris decurrens* and *A. lonchitica* which are common in the Coal Measures.

In West Cumberland mixed measures lying above the Udale and almost up to the Harrington Four Foot Coal are regarded, from their fossil content, as belonging to the highest zone of the Millstone Grit Series. In the absence of particular goniatites and where stratigraphical evidence of the existence of the measures is wanting it has been deemed advisable to omit Millstone Grit from certain maps both in West and in North-East Cumberland.

COAL MEASURES

The sequence of Coal Measures is incomplete in Cumberland, Northumberland and Durham, for some of the upper measures were removed by denudation before the covering Permian and Triassic rocks were laid down. In Cumberland, however, the Productive Measures, with the chief workable coals, are succeeded by the Whitehaven Sandstone—a group of purplish sandstones and shales—which, with the red rocks near Canonbie, may represent most of the Upper Coal Measures of the Midlands.

Grey is the prevalent colour in the Coal Measures, the sandstones as a rule being light grey, though they weather buff or yellow, while the clay rocks exhibit all shades from black to almost white. On the whole, clay rocks—shales and mudstones—predominate in Cumberland and sandstones in Northumberland and Durham. Coal itself, the most valuable constituent, seldom averages above 5 per cent. of the Coal Measures.

Some of the shales contain nodules or bands of clay-ironstone which were at one time mined near the crop as an iron-ore. Sandstones provide building-stones and grindstones; some, of high silica and low alkali content, known as ganisters, furnish refractory material for furnace linings, etc. Fireclays, which are also low in alkalies, are used in the manufacture of firebricks and sanitary ware. Building-bricks are made from the shales and mudstones. Most of the coals are of the bituminous class suitable for household fuel, steam raising, gas and coke making, though certain seams provide material more suitable for particular purposes than others. There is neither anthracite nor high-grade steam coal. Cannel, of some importance in the gas industry when luminosity of the burning gas itself was essential, is a fairly common constituent in some of the coal seams, and also occurs alone.

At the time of formation the northern coalfields were probably part of a large delta. Subsequent earth-movements, however, gently folded and tilted the rocks thus formed, while faulting further displaced them. The upraised portions were weathered away so that to-day the coalfields are separated by large stretches of older rocks (see Fig. 3, p. 8).

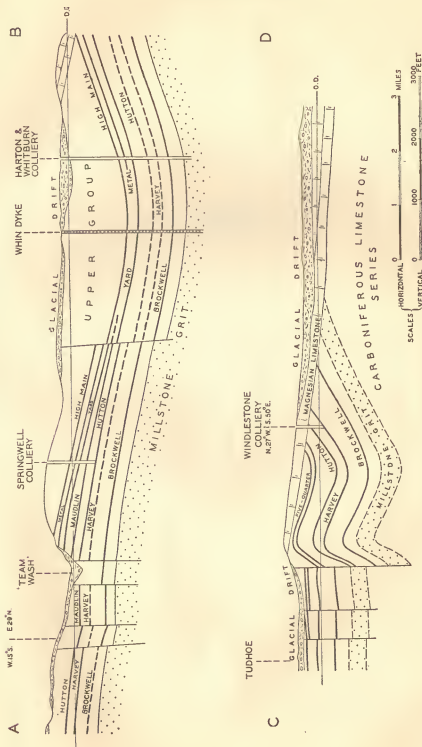


FIG. 17. Sections across the Northumberland and Durham Coalfield

Northumberland and Durham Coalfield.—In Northumberland and Durham the Coal Measures attain a maximum thickness of about 2500 ft, and may be divided as follows:

Upper Group: mostly sandstones (not red) with a few coals
Middle or Main Productive Group: many workable seams
Lower or Ganister Group: coals thin and few

The Lower or Ganister Group, about 200 ft thick, is characteristic of Durham, the Northumberland equivalents being insignificant. The Tow Law Ganister at the base is almost equal to the best 'Sheffield Blue' and has been much worked; nothing quite so good is known amongst the numerous ganisters and siliceous sandstones of the Millstone Grit and the Carboniferous Limestone Series.

The Middle or Main Productive Group, from the Brockwell up to the High Main (Shield Row of Durham), includes all the best coals, of which fifteen to twenty seams are present (*see* Fig. 20, p. 50). In Northumberland steam-raising and house coals are the rule, changing to coking and gas coals in Durham, particularly in the lower part of the group towards the west. Most of the thicker seams are nearing exhaustion, for production has been active since at least Elizabethan times.

In the Upper Group, coals are less numerous, massive sandstones being predominant. The well-known 'Newcastle Grindstone' appears here, the quarries south-east of Newcastle working strata totalling 120 ft in thickness. On the north bank of the Tyne the 'Seventy Fathom Post' occurs at this horizon. Both represent purely local developments. Amongst the coals the highest known at outcrop is that at Clousden (Closing) Hill, south-east of Killingworth, which lies about 1000 ft above the Hutton Seam. Higher coals are only known from records of shafts.

The Coal Measures as a rule dip gently to the east, but beyond the coast the strata may begin to rise again, while in South Durham a sharp uprise brings the coalfield to an end beneath the Magnesian Limestone (*see* Fig. 17).

Normal faulting is the rule, and usually follows one or other of two main trends. The major faults range within 25° of east and west: of these the 'Ninety Fathom Dyke', north and west of Newcastle, the Butterknowle Fault at the southern end of the Durham field, and the Stublick Fault which prolongs the main coalfield westwards along the Tyne as a string of outliers, are worthy of mention. The second set, trending north by west, is of less importance, though there are numerous examples.

Two groups of igneous dykes are known: (1) those trending north of west, and presumably of Tertiary age, as, for example, the Acklington Dyke which has been traced from the north end of the coalfield beyond the Cheviots into the heart of the Southern Uplands; and (2) a group of quartz-dolerites of Whin Sill type, ranging south of west, which are probably of late Carboniferous age since they do not penetrate the Magnesian Limestone.

Cumberland Coalfield.—The Coal Measures of West Cumberland fall into two natural subdivisions, the Productive Measures below and the Whitehaven Sandstone Group above.

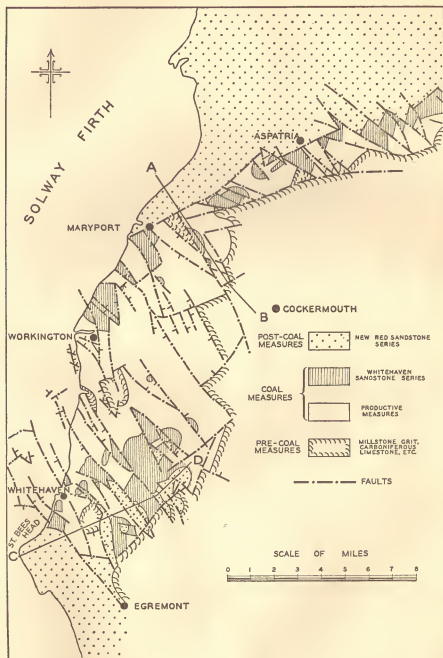
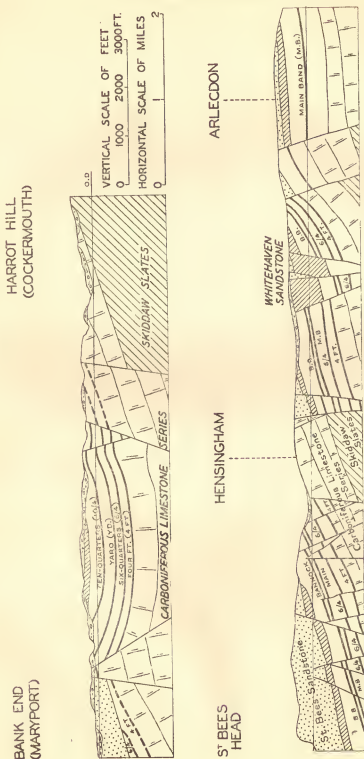


FIG. 18. Sketch-map of the main portion of the Cumberland Coalfield



The Productive Measures are about 1000 ft in thickness and contain the principal seams of coal. Some of the sandstones are fairly persistent and are then named after the underlying coal, but more often they are inconstant and pass laterally into argillaceous rocks.

The more important coals are shown in Fig. 20 (p. 50). The chief seam in the southern part of the field around Whitehaven is the Main Band. Northward, about the Derwent Valley, it splits, but otherwise retains its good qualities for some miles; then by further splitting, thinning or increase in 'dirt', which sets in first in the lowest member—the Cannel Band—but in turn affects the Metal Band and Thirty-Inch Coal, the whole of this composite seam becomes valueless. The deterioration is compensated for by an improvement in the Yard Band, a seam of little consequence in the south, better in the middle tract, and excellent in the north. Lower seams than these attain their best development between Maryport and the River Derwent; farther south they are of some value, but to the north may be neglected. Of the seams above the Main Band the Bannock in the south and the Ten-Quarters farther north are the most important.

The coals are bituminous and suitable for general fuel, coke and gas making. Most of them have a few inches of impure cannel next to the roof, but in the Main Band a layer of cannel is almost invariably present in the lower third of the seam.

The Whitehaven Sandstone Group is mainly arenaceous, but becomes rather less so to the north and north-east. The total thickness is unknown; as much as 600 to 700 ft may be present in the southern tract, and over 1000 ft near Aspatria. The rocks as a whole are barren, though they contain coals of workable thickness and quality near Maryport. Purple and reddish-grey in various shades are the prevalent colours, but some of the shales, especially where the group is coal-bearing, are grey or blue. Two thin *Spirorbis* limestones are known in the south—where one has been locally converted to haematite; these have not been identified elsewhere in this coalfield, but it is interesting to record that one occurs near Canonbie.

Tilting, begun early in the Carboniferous Period, was renewed before the Whitehaven Sandstone was laid down; and that formation rests unconformably on the Productive Measures, the transgression being most marked in an easterly and north-easterly direction. Shallow folding accompanied by some faulting followed the deposition of the Whitehaven sandstone, but before the advent of the Permian.

Faults in the Cumberland Coalfield, mainly along north-west to south-east lines, are numerous (see Figs. 18 and 19), and these disturbances add considerably to the cost of mining. Some of the other faults range east-north-east to west-south-west. These frequently downthrow to the north, and where they bring Coal Measures against the Limestone Series are spoken of as 'coal-faults'. Much of the faulting is post-Triassic and with the present seaward tilt of the measures must be attributed in part to Tertiary uplift of the Lake District.

Igneous intrusions are unknown in the coalfield of West Cumberland.

Correlation between the Coalfields.—No single coal seam or other stratum has been proved to be common to the two coalfields on either side of the North Pennines. Palaeontological evidence suggests however to Dr. Stubblefield that the Bolton Marine Band, formerly thought to occur near the base of the Whitehaven Sandstone Series but now known to occur high in the Productive Measures, is to be correlated with the Ashington and Ryhope

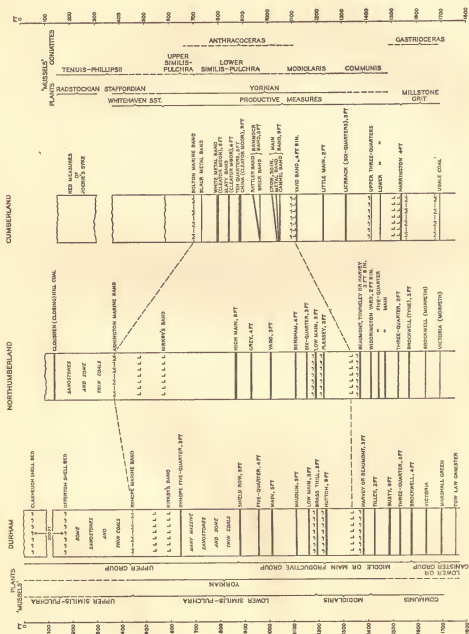


FIG. 20. Vertical sections of the Northern Coalfields

marine bands which occur about 500 ft above the High Main Coal of Northumberland and the Shield Row Coal of Durham, respectively. The fossils from these bands enable correlation to be made with Skipsey's Marine Band of Scotland and with the Mansfield and its equivalent marine bands in the English coalfields.

The measures can be divided into zones by non-marine lamellibranchs (see Figs. 20, 21), usually referred to by miners as 'mussels', which belong to the genera *Anthracosia*, *Anthracosphaerium*, *Anthraconaia*, *Anthraconauta*, *Carbonicola* and *Naiadites*. The shells of these animals may occur scattered through the mudstones or aggregated as mussel-bands. One of the latter is usually to be found 10 to 30 ft above the Yard Band in Cumberland, and forms a very useful index of position about mid-way in the Productive Measures. In the Northumberland-Durham field the Hopkins Shell Bed is equally important. One distinctive features of this shell-bed is the frequent presence of the ostracod *Geisina arcuata* in association with shells. In the same coalfield, some 40 ft above the Beaumont Seam, towards the middle of the zone of *Anthraconaia modiolaris*, a marine band occurs which is now recognized as the Harvey; and above the Yard Seam in the Cumberland Coalfield lies the correlative Solway Marine Band (both shown in Fig. 20 by the symbol L).

In the higher measures, shells representing the zone of *Anthraconauta phillipsii* have been found in the Whitehaven Sandstone Series associated with a band of *Spirorbis* Limestone at Millyeat, near Frizington, and *A. phillipsii* with *A. tenuis* from Jockie's Sike in the Canonbie Coalfield near the Border. In the north-eastern coalfields *A. phillipsii* has been recorded from 1380 ft above the Hutton Coal at Claxheugh associated with *Naiadites*, *Geisina? subarcuata* (Jones) and *Euestheria*, but the faunal evidence suggests that this Claxheugh Shell Bed is just below the boundary between the Upper *similis-pulchra* and *phillipsii* zones.

Plant remains are fairly common, more so in the eastern field than in Cumberland. In both fields they indicate that the greater part of the grey measures should be referred to the Yorkian subdivision of the Coal Measures. In Northumberland and Durham the Yorkian flora appears not far above the Brockwell Coal (see Fig. 20). In the latter coalfield one of the most prolific plant horizons is that below the Hutton Coal. In Durham, Yorkian species are still prominent in the highest known Coal Measures seen at Claxheugh (Fig. 20).

In Cumberland plants obtained from a band about 150 ft above the base of the Whitehaven Sandstone Group at Whitehaven are definitely Staffordian; they include *Linopteris muensteri* and *Sphenophyllum emarginatum* (see Plate IV), and are referable to the lowest or Blackband subdivision of the Staffordian. Little is known of higher measures; but if, as we believe, the red measures of Canonbie are in upward sequence with the Whitehaven Sandstone, then the whole of the Staffordian would be represented in Cumberland; for at Jockie's Sike, on the English side of the Border near Canonbie, the plants are indicative of horizons comparable with the Keele Beds of the Midlands, which are referred to the Radstockian (see Fig. 20).

Fossils other than the groups mentioned are too localized to be of much use to the stratigrapher, but reference may be made to fish-scales at the Mussel Bed horizon in Cumberland, to the numerous fish and amphibian remains in the roof of the Low Main Coal east of Newcastle, and to the fish, arthropod and insect remains above the Ryton Ruler Coal between the Hutton and Beaumont seams.

IGNEOUS ROCKS ASSOCIATED WITH CARBONIFEROUS STRATA

The igneous rocks associated with the Carboniferous strata of Northern England (see Fig. 14, p. 34) fall into two classes: (1) volcanic, and (2) intrusive.

The volcanic rocks are confined to the Lower Carboniferous and are mainly olivine-basalts. They include the Kelso Traps beneath the Cement-stones in the Cheviot region, lavas and tuffs near the western end of the Border between Bewcastle and Kershopefoot, and Cockermouth Lavas—a thick series of olivine-basalts between the basal conglomerate and the Seventh Limestone of Cumberland—and the Scarlet Point Volcanic Series of the Isle of Man. The last named are the highest of the Carboniferous volcanic

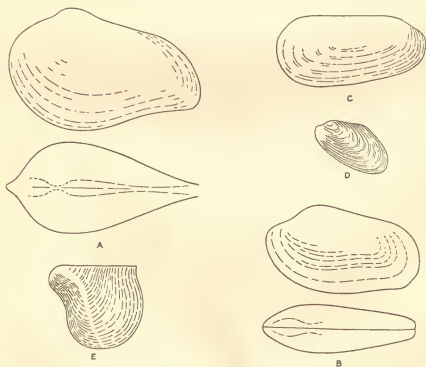


FIG. 21. Non-marine lamellibranchs from the Coal Measures
(All natural size)

A, *Carbonicola pseudorobusta* Trueman; B, *Carbonicola communis* J. H. Davies and Trueman; C, *Anthraconaia modiolaris* (J. de C. Sowerby); D, *Anthraconauta phillipsii* (Williamson); E, *Naiadites quadratus* (J. de C. Sowerby)

rocks in the region and follow the Poolvash Limestone; they consist of porphyritic olivine basalts and basaltic tuffs and agglomerates so much disturbed by overthrusting that their actual relationship to the adjacent rocks was long in doubt.

The intrusive rocks comprise sills and dykes. Some of the latter are of Tertiary date and will be dealt with at a later stage (p. 62). Those with which we are here concerned are all quartz-dolerites and are dark rocks of rather fine texture usually devoid of phenocrysts. They are exceedingly tough and make excellent roadstones. The most important is the series of lenses known collectively as the Whin Sill, which crops out at intervals right across Northumberland and North-East Cumberland, along the Pennine escarpment and in Teesdale. Throughout the greater part of this distance a general position is maintained in the heart of the Carboniferous Limestone Series; such transgressions as occur, though abrupt, are of relatively small amount and take place along joint and fault planes. It is not surprising, therefore, that many geologists, including Phillips, regarded the mass as a contemporaneous lava flow, though the intrusive origin was advocated as early as 1826 by Sedgwick, and established by Tate about 1870. In spite of the fact, however, that the whin runs for miles at about one horizon, it is evident that great changes in position do occur, for in the small coalfield at Midgeholme it lies in the Coal Measures.

A maximum thickness of 240 ft of whin has been recorded from the Burtree Pasture lead mine in Weardale, but the average may lie between 80 and 100 ft. In drift-free areas it gives rise to bold escarpments such as may be seen in Teesdale, along or north of the Roman wall, and again in the Belford country (see Plate III, facing p. 36); it forms sea cliffs in the Farne Islands, and is responsible for many waterfalls, including High Force.

In the Midgeholme to Weardale area, however, where the Whin Sill is best developed, it forms no escarpments.

The dykes of this period range roughly east-north-east; one of the best examples is the Hett Whin Dyke, which is traceable for twenty miles across the Coal Measures of South Durham, though there are several others in the Northumberland-Durham Coalfield and in the adjoining limestone country. The echelon arrangement of these dykes is striking.

VI. PERMIAN AND TRIASSIC SYSTEMS

THE ROCKS which follow the Coal Measures unconformably are usually placed in the two systems of Permian and Trias. Both contain salt, anhydrite and gypsum; but dolomite, in large beds at any rate, is confined to the lower or Permian system. So far as north-western England is concerned, however, the old name of New Red Sandstone for the combined systems would yet be appropriate, for there appears to be stratigraphical continuity, and there are many similarities in lithology, between the upper and lower parts; fossils are too few to be of much assistance in correlation.

Since Durham has been considered the type area of the Permian formation in Britain, the description of the Permo-Triassic rocks may appropriately be commenced with those of that county.

EAST OF PENNINES

The Magnesian Limestone crops out almost continuously on the Durham coast from South Shields to Hartlepool and extends westwards to within three miles of Durham. In addition there are three tiny outlying patches of the lowest beds of the formation in the Tynemouth and Cullercoats area of south-east Northumberland (see Fig. 22, p. 55). The series begins with the Yellow Sands (see Fig. 24, p. 59), a discontinuous, incoherent, false-bedded sand, possibly of aeolian origin. The greatest thickness of Yellow Sands so far recorded is 180 ft. Above this lies a 15-ft bed of Marl Slate (equivalent to the *Küpferschiefer* of Germany) rich in fish remains, plants and amphibians, and containing galena and zinc blende. This is followed by the Magnesian Limestone, abundantly exposed in quarries and coast-sections. The Magnesian Limestone is sub-divided by C. T. Trechmann into Lower, Middle and Upper divisions, which together have a thickness of about 800 ft. The rock is not wholly composed of the mineral dolomite, but is a variable mixture of dolomite and calcite. As non-magnesian limestones frequently occur at the base, and anhydrite beds lie in the uppermost dolomites, for instance at Hartlepool, it seems that deposition took place in waters subject to evaporation. The fossils, which are found mainly in the Middle group of the Limestone, consist of dwarfed forms of gastropods, lamellibranchs and brachiopods of Zechstein type.

The general grouping of the Permian rocks in the outcrop area, from S. Shields southwards to Hartlepool and thence south-westwards to Darlington, is as follows:

Magnesian Limestone	Upper Limestones	Hartlepool and Roker Dolomites
		Concretionary Limestone
	Middle Limestones	Flexible Limestone (local)
		Brecciated Limestone
	Unconformity	
	Lower Limestone	
Marl Slate		
Yellow Sands		

The Lower Limestone is a blue-grey, evenly bedded rock, with few or no fossils, except in South Durham, where it thickens and yields well-preserved molluscs, brachiopods and polyzoa. The Middle or Shell-Limestone Group

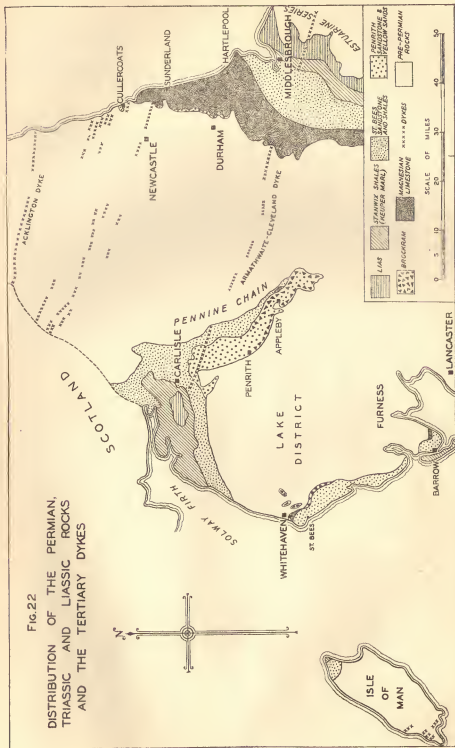


FIG. 22. Sketch-map showing the distribution of the Permian, Triassic and Liassic rocks, and the Tertiary dykes

is of greater interest, for locally it is abundantly fossiliferous, and moreover presents problems in brecciation of a special character. It contains a reef with abundant algae and bryozoa, starting north-west of Sunderland and running southwards till it passes underground about Castle Eden: it emerges on the coast at Blackhall Rocks east of Castle Eden; and farther south at West Hartlepool the top of the reef was reached in a recent boring, about 100 ft below the surface.

The reef rests unconformably on Lower Limestone, and the knolls widen and thicken southwards till they are about three miles wide and some 320 ft thick (see Fig. 23). The lower beds are often highly fossiliferous, with large molluscs and brachiopods such as *Productus horridus*, *Spirifer alatus* and *Dielasma elongatum*. Higher in the reef impoverishment sets in, the forms are dwarfed and many species die out altogether. To the west the reef seems to pass into bedded dolomites, while to the east it is flanked by unfossiliferous breccias in some places showing a slickensided contact. Dr. Trechmann suggests that the slipping may have been occasioned by the removal of large masses of gypsum. The breccias themselves present problems of much complexity. There are three main types—all of secondary formation. The earliest seems to have been the 'cellular breccia', where the fragments, and not the matrix, have often weathered completely away. Professors Hickling and Holmes consider that the small size of the fragments—they are rarely over an inch across—and their sharp angularity point to an *in situ* derivation from a thin-bedded, fine-grained rock, shattered by hydration of interbedded anhydrite to gypsum, followed by calcite replacement of the matrix of crushed limestone, and leaching out of the fragments.

The 'massive brecciation' is clearly a later event, for amongst the rocks affected are the 'cellular breccias' themselves. The blocks are in places incompletely separated, they may be 3 ft or more across, and they are more calcitic than the matrix: such a concentration of calcitic material may perhaps have brought about the breaking up of the rock. The 'gash-breccias' are more readily accounted for: they are obviously a late phenomenon due to the collapse of the roofs of natural cavities or the walls of deep fissures made by the circulation of subsoil water. Parallel cases are common in most limestone areas.

The Upper Group starts with the 'Flexible Limestone', a North Durham phase which is replaced by hard platy dolomites round Hartlepool. Over this is the Concretionary or Cannon Ball Limestone, conspicuous in North Durham but dying out to the south. This very odd-looking rock has attracted attention from the earliest days of geology, but we are still far from a satisfactory explanation of its origin. Excellent exposures were seen in the great Fulwell quarries north of Sunderland, where concretionary structures in almost endless variety were studied. Amongst them two main groups are prominent, (a) spheroidal or 'cannon-ball' concretions, of all sizes up to 2 or 3 ft across, and (b) reticulate structures, wherein layers composed of parallel rods (arranged either at right angles or obliquely to the stratification) alternate with evenly bedded stone. Stellate cavities are not infrequent, and suggest the original presence of aggregates of twinned crystals of gypsum.

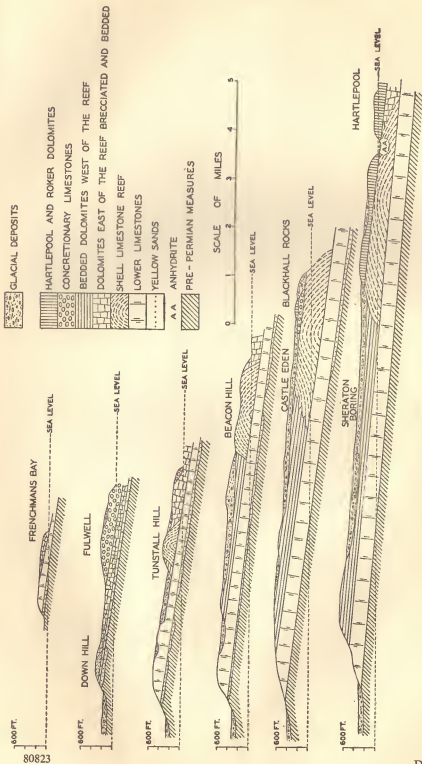


FIG. 23. Sections across the Permian rocks of Durham
(Mainly based on Dr. C. T. Trechmann; for positions see Fig. 16, Sections 1 to 6)

Two features are common to all the concretions: they are definitely more calcitic than the yellow, powdery matrix between them, and bedding planes pass through concretions and matrix. The bewildering variety of form is probably due to the varying composition of the original rock: segregation and incipient crystallization in such a medium are no doubt contributory factors, but precisely how the process worked is not yet known.

Overlying the concretionary beds are the Hartlepool and Roker dolomites, about 100 ft thick, massive and oolitic. In the Upper group fossils are not generally abundant, but in places mollusca such as *Schizodus* are plentiful, accompanied by the problematical organism *Filograna*?

The following sequence is found in south-east Durham, south of the conjectured Darlington Fault which extends from Darlington to Hartlepool in a curved line convex towards the north-west:

	Approx. thick- ness in ft
Triassic Sandstones	—
Permo-Triassic Marls	300-350
Upper Anhydrite	10
Marl	20
Main Salt	100
Main Anhydrite	45
Upper Magnesian Limestone, with <i>Filograna</i> ?	75
Lower Salt	60
Lower Anhydrite }	
Lower Magnesian Limestone: with much anhydrite in some areas	600-700
Basement Beds, sometimes conglomeratic and with a development of the Marl Slate, especially in the west ..	Very variable

Definite correlation between these developments north and south of the conjectured Darlington Fault is not possible. The Marl Slate, for example, may be purely a facies feature. It is generally thought likely that strata now removed from above the Magnesian Limestone of the South Shields-Hartlepool belt contained representatives of the Saliferous Marls, and that the alternating beds of evaporites near the base of these marls and in the top portion of the dolomite may be to some extent the time equivalents of parts of the Upper Limestones of C. T. Trechmann.

The thick beds of salt and anhydrite in the Stockton and Middlesbrough area are the raw materials of a great chemical industry. The main salt bed dwindles westwards towards Billingham, but the underlying bed of anhydrite thickens to 30 ft in the same direction and is worked extensively as a source of sulphur and cement.

The Triassic rocks of south-east Durham are covered by drift, and exposures are very rare. Most of our knowledge of them comes from borings to the underlying salt. They consist mainly of red sandstones with partings of red and grey variegated marl and appear to pass downwards without a break into the much more argillaceous and mineralized Saliferous Marls.

WEST OF PENNINES

West of the Pennines the Penrith Sandstone of the Vale of Eden constitutes the lowest member of the New Red Sandstone. It is usually a coarse pinkish



A.—BLACKHALL ROCKS—A SEA-STACK OF BEDDED DOLOMITE ON BRECCIATED REEF—FIVE MILES NORTH-WEST OF HARTLEPOOL



B.—CANNON-BALL LIMESTONE, FULWELL QUARRY, SUNDERLAND



A.—MAGNESIAN LIMESTONE AND BROCKRAM OVERLYING WHITEHAVEN SANDSTONE, SALTOM BAY, WHITEHAVEN



B.—ST. BEES SANDSTONE, MCKAY'S QUARRY, SALTOM BAY, WHITEHAVEN

rock, many of the grains are of 'millet-seed' type, suggestive of origin as desert sand, and in some cases the silica cement is in optical continuity with the sand grains. Breccias or 'brockrams' occur at the base and towards the

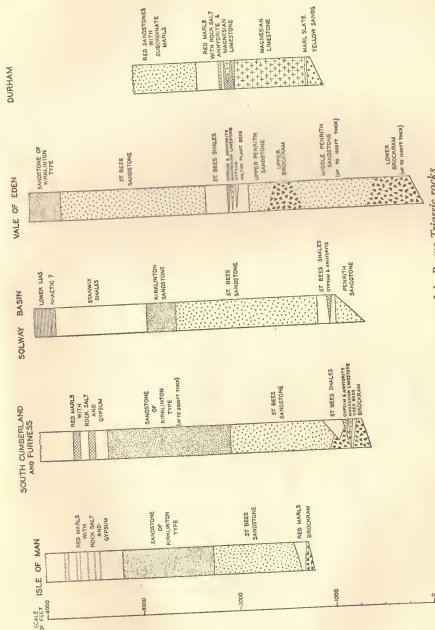


FIG. 24. Vertical sections of the Permo-Triassic rocks

top of the formation near Appleby (see Vale of Eden, Fig. 24). Fragments in the lower one are derived entirely from Carboniferous strata, but the higher breccia contains older rocks also and, incidentally, rare pebbles of

the Whin Sill (p. 53). This difference in pebble content has been attributed by Professor Kendall to movement of the Pennine Fault during the interval between the formation of the two brockrams, but it may be due to different sources of supply, for it appears to be local in character.

Grey or yellow dolomitic shales and sandstones succeeding the Penrith Sandstone of the Appleby region have yielded fossil plants such as *Alethopteris goepperti*, *Ullmannia selaginoides* and *Sphenopteris dichotoma*. These so-called Hilton Plant Beds are followed by a thin representative of the Magnesian Limestone. Farther north, however, the Penrith Sandstone passes upward by well-stratified alternation of types of sediment into the St. Bees Shales, neither Hilton Plant Beds nor Magnesian Limestone being present. Southward the Penrith Sandstone and brockrams die out; and in the Furness district a bed of Magnesian Limestone, 63 ft thick, forms the local base of the New Red Sandstone.

On the West Cumberland coast, at Barrowmouth near Whitehaven (see Plate VI), a coarse brockram rests with marked unconformity on Whitehaven Sandstone (p. 46), but above this there appears to be a perfect upward passage thus: Brockram→Magnesian Limestone→St. Bees Shales→St. Bees Sandstone. Inland the Magnesian Limestone dies out, and eventually hundreds of feet of brockram—contrasting with the 2 or 3 ft at Barrowmouth—appear to replace all the lower part of the New Red Sandstone up to, and possibly including, some of the St. Bees Sandstone. In the same direction the Brockram oversteps the whole of the Carboniferous. The brockrams of West Cumberland vary considerably in boulder content. They may be accounted for by assuming that the brockram represents scree of neighbouring valleys with different rocks, swept out by occasional torrents to form gravel fans that intermingled in the lower ground: in places the fans impinged upon lagoons in which the Magnesian Limestone, or the St. Bees Shales with their bed of gypsum, were being laid down.

In south-west Cumberland beneath the St. Bees Sandstone plant beds and thin bands of fossiliferous Magnesian Limestone occur between the lower and upper brockrams.

In the Maryport region the brockram is represented by a thin basal conglomerate frequently less than one foot in thickness, and the St. Bees Shales are more sandy than usual; farther north again, around Carlisle, normal St. Bees Shales with gypsum pass upwards into the red St. Bees Sandstone, which gradually gives place, by the decrease in the number and thickness of shale bands, to the wholly arenaceous, variegated Kirklington type of sandstone with its occasional belts of wind-worn grains. The last formation in turn passes upwards into the Stanwix Shales, a series of red shales and marls with subordinate bands and occasional beds of dolomitic limestone.

Beneath a thick cover of drift at the north end of the Isle of Man the Carboniferous Limestone is succeeded by a conglomerate followed by red shales, sandstones, and shales with salt and gypsum (see Fig. 24.) There can be little or no doubt that these rocks represent the brockram, St. Bees Shales, St. Bees Sandstone, and Stanwix Shales of Cumberland.

The Stanwix Shales are generally believed to be equivalent to the Keuper Marls of the Midlands, and the St. Bees Sandstone is usually regarded as Bunter. On the other hand, the Magnesian Limestone is classed as Permian, and where it rests on Brockram that rock cannot be younger than Permian. In Cumberland, and to some extent in the Isle of Man, there appears to be not only a perfect vertical passage from one rock to another, but in the case of the Brockram a lateral passage also. Any division of the New Red Series into Permian and Trias must therefore be arbitrary.

The irregularity of distribution—the Penrith Sandstone being almost confined to the environs of the Eden Valley, the Magnesian Limestone, dying out northwards in Edenside and eastwards from Whitehaven, being absent from many places and present only in patches north and south of the Lake District, and the behaviour of the Brockrams—all point to unsettled conditions, especially before the advent of the St. Bees Shales. Furthermore, similar deposits are not necessarily of the same age. Close correlation, therefore, cannot be expected.

VII. JURASSIC SYSTEM

THE JURASSIC ROCKS that succeed the Trias near Middlesbrough fall into another regional district—that of East Yorkshire and Lincolnshire. The only remnant left of this great system of rocks in 'Northern England' is to be found near Carlisle (*see* Fig. 22, p. 55).

Dark shales with bands of bluish argillaceous limestone form an outlier on the relatively high ground about Great Orton to the west of Carlisle, and have been penetrated in several old wells. Exposures at the surface are poor but are sufficient to prove the rocks to belong to the Lower Lias. There is no direct evidence as to the existence of Rhætic Beds between the Lias and the Stanwix Shales, but in view of the fact that this formation, though thin, marks a widespread submergence at the end of Triassic times it may exist beneath the Glacial drift round the Great Orton outlier.

VIII. IGNEOUS ROCKS OF POST-TRIASSIC AGE

THE ONLY DEFINITE EXAMPLE of an igneous rock affecting post-Carboniferous strata in our district is the Cleveland-Armathwaite Dyke (*see* Fig. 22, p. 55). In Cumberland the dyke cuts Permian and Triassic sandstones between Renwick and Dalston, but it has not been located in the Lias west of Carlisle—though this is not surprising as, apart from Glacial drift, it frequently fails to reach the surface—but is supposed to link up with a Scottish dyke across the Solway on the one hand and with the Cleveland Dyke of Yorkshire on the other. The rock is a tholeiite or augite-andesite with a devitrified glassy base.

Similar tholeiites of the same general trend, namely, west-north-west to east-south-east, occur in Northumberland and Durham, the most northern being the Acklington Dyke. Together with the Armathwaite Dyke they are believed to be part of a swarm of basic dykes associated with the Tertiary complex of Mull.

Near Castletown, in the Isle of Man (*see* Fig. 22, p. 55), a group of olivine-dolerite dykes, which trend north-west, are also believed to be of Tertiary age.

IX. PLEISTOCENE SYSTEM

IN THIS SYSTEM are included deposits of the Glacial Period such as boulder clays, and recent accumulations of the Post-Glacial Period such as blown sand and alluvium. The terms Glacial and Post-Glacial, however, when related to age as distinct from physiographical conditions, are of local rather than of general application.

GLACIAL PERIOD

The land mass that came into being at the end of the Cretaceous Period probably persisted in our area throughout the greater part of the Tertiary era. On it a river system was gradually formed and the present hills and dales were roughly carved out before the cooling of the climate, which led to the gradual development of snowfields, culminated in the Great Ice Age of the Pleistocene Period.

The distinctive features by which the aforetime presence of ice over this part of Britain is recognized are partly the result of erosion and partly of deposition.

Glacial erosion caused the removal of weathered rock debris and the grinding, polishing, striation and 'plucking' of bare rock surfaces; 'plucking' in particular having contributed to the formation of the deep flat-bottomed 'U'-shaped valleys with 'hanging' side-valleys, and to the peculiar rounded valley heads known as combs or corries. The Lake District abounds in excellent examples of these features, but they are not so well marked in the Pennines and the Cheviots.

The glacial deposits include boulder clays, made more or less directly by the action of moving ice, and the gravels, sands and laminated clays which represent debris carried by the ice but sorted by, and often accumulated in, water resulting from the melting of ice. The stones in the boulder clays and gravels are commonly derived from more or less distant sources; they serve to indicate the course taken by the ice, as, for example, boulders of Shap Granite which have reached Scarborough via the Stainmore Pass, or boulders from Carrock Fell now found in West Cumberland, and so on (*see* Fig. 25).

Both erosion and deposition have contributed to the formation of lakes; the former by the irregular over-deepening of valley floors into rock basins, as, for instance, at Haweswater, and the latter by the damming of valleys by barriers of drift, such as occurs at Ennerdale Water.

Boulder clay gives rise to two main types of topography: (a) featureless ground, and (b) ridges and hollows. The former is characteristic of much of Durham and Northumberland, and of the higher ground elsewhere. Ridges may be long, as in parts of West Cumberland, or in the form of drumlins which are smooth hillocks, in plan typically oval, and in elevation with one end steeper and blunter than the other. The longer axis is parallel to the direction taken by the moulding ice, and the steeper or 'stoss' end faces 'upstream'. They therefore serve a useful purpose in determining

directions of ice movement. In the eastern part of our area the best examples of drumlin topography are to be found in the valley of the Tweed below Coldstream, but drumlins are common and well developed in the country bordering the Lake District.

There are many varieties of boulder clay: extremely stiff, or very sandy; almost stoneless, or so stony as to constitute a gravel with a clayey matrix;

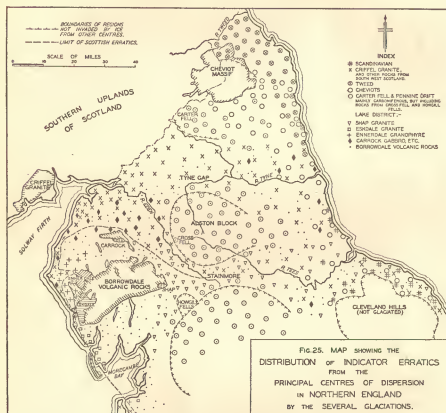


FIG. 25. Sketch-map showing the distribution of the indicator-erratics from the principal centres of dispersion

containing many far-travelled erratics, or made up of comparatively local materials; of any colour, though grey and red are most common. The stones are frequently scratched and subangular, but one characteristic only is common to all the varieties, and that is the unsorted nature of the constituents. As a typical example may be cited a *red* boulder clay which masks part of the outcrop of the *grey* Coal Measures of West Cumberland. Much of its material is derived from the Trias, but boulders of Criffel Granite occur as erratics. This boulder clay is arranged in ridges and drumlins which conform to the direction of others, of grey boulder clay, on the landward side, in which erratics from Carrock Fell are present. From these



A.—GLACIATED PAVEMENT OF HENSINGHAM GRIT, BARFS QUARRY,
DISTINGTON, NEAR WHITEHAVEN



B.—GLACIAL CHANNEL, WORKINGTON ROAD, WHITEHAVEN



A.—BOULDER CLAY WITH CONTORTED FRAGMENTS OF COAL
MEASURES SANDSTONE, EAST CLIFF, TYNEMOUTH
(*Reproduced by permission of the late Professor E. J. Garwood*)



B.—KETTLE-HOLE IN GLACIAL GRAVELS, NEAR CORNHILL,
NORTHUMBERLAND

facts we infer that ice emanating from the Lake District was deflected southwards by, and united with, an ice sheet from the Southern Uplands of Scotland.

The topography of the country occupied by sands and gravels is much more diversified than that shown by boulder clay. Some of the deposits are flat-topped, steep-sided and often lobate-fronted; these are obviously of deltaic origin. In some cases the back slope of a delta is sharp and straight; we then infer that the material was deposited directly from the ice into an impounded lake. Others, with no such ice-contact slope, were fed by streams issuing from the ice, by land drainage streams or at the lower ends of overflow channels connecting one lake with another. Some of the deltas, however, were not completely built up to lake level and their surfaces are frequently hummocky.

Kames form another type of sand and gravel deposit. These are usually irregular ridges pitted with roughly circular hollows which may now contain ponds (*see* Plate VIII, facing p. 65). They were formed directly from the debris-laden ice along its shrinking margin—the ridges marking temporary halts during retreat, and the pits or kettle-holes masses of ice that were then incorporated in the gravels. Kames may be regarded as a closely linked series of direct or outwash deltas, or of their land equivalent, outwash fans.

Examples of these deposits and associated phenomena are common throughout the region of Northern England, but attention may be drawn to the deltas around Ennerdale, to the kettle-holed kame on the coast south-west of that lake, to the Brampton district, to the Bradford Kame of Northumberland and to the Bride Hills of the Isle of Man—all of which have been described in Geological Survey memoirs.

From the superposition of distinctive boulder clays—often separated by sands and gravels—the sequence of events during the Glacial Period is fairly well known.

Dr. Trechmann's researches suggest that the onset of glacial conditions on the north-east coast was heralded by the arrival of Scandinavian ice. Patches of boulder clay with characteristic Norwegian erratics, such as rhomb-porphry, etc., along with comminuted sea shells and peaty matter, have been rammed into fissures in the Magnesian Limestone cliffs of Durham, and so have escaped the scour of later ice-movements. Then came a period during which a fine-grained deposit, believed to be of aeolian origin and resembling the 'loess' of the Continent, was formed. Some observers believe that subsequently *northern ice*, i.e. from the Cheviots, Tweed and east Scotland, twice occupied the coastal regions of south Northumberland and Durham, with an intervening stage during which *western ice*, from the Lake District and the south-west of Scotland, and *local ice*, from the Pennines and Cheviots, reached that coast (*see* Fig. 26). Others, however, maintain that only one British glaciation affected this region, with changes in the direction of the ice.

West of the Pennines the evidence of the earliest movements has been largely obliterated, but three episodes can usually be recognized, each

corresponding to two stages—when the advancing ice laid down boulder clay, and when sands, gravels and laminated clays were deposited by the melting ice. During the earliest of these three episodes—the ‘Early Scottish Glaciation’—ice emanating from the south-west of Scotland, bringing boulders of Criffel Granite, etc., was dominant in Edenside and the Solway, and led to the invasion of the district east of the Pennines by *western ice*.

Then came the ‘Main Glaciation’—so called because its deposits are the most widely spread in Cumberland and Westmorland—in which Edenside and the Solway formed a great reservoir for the eventual dispersal of Lake District and Pennine ice. During this phase some of the Lake District ice moved southwards alongside Scottish ice. This Main Glaciation corresponds to the second movement of *northern ice* down the north-east coast. Extensive deposits of sand and gravel and laminated clays were formed during the retreat of the ice-sheet both east and west of the Pennines. The Main Glaciation was succeeded by a period sufficiently mild to permit the growth of peat; some of this has been preserved beneath the Upper Boulder Clay at St. Bees.

A renewal of cold conditions led to another invasion of Cumberland by ice from Scotland. This glaciation, usually spoken of as the Scottish Re-advance, was not sufficiently powerful, as a rule, to do more than slightly modify, or lightly blanket, the relics of its predecessors. It seldom invaded more than the low country between the foothills and the sea (see Fig. 26), so that much of the country as we now see it, except for minor modification of the valleys and coastline, is substantially the same as at the end of the Main Glaciation.

With the melting of the ice at any stage temporary glacier-dammed lakes were often formed. By linking up the gravel deltas formed in these old lakes with the levels of now deserted marginal or direct overflow channels that drained them, it has been shown that successive chains of lakes existed. The evidence provided by these channels and deltas, used in conjunction with the frontal or outwash deposits from the ice, enables us to determine the position of the fronts of the ice at various stages of retreat.

Glacier-lake phenomena are particularly well developed in our region, where many of them are associated with the retreat stages of the Main Glaciation.

Before the Glacial Period the land stood higher than it does now, for pre-Glacial valleys as far as 141 ft below present sea-level are known in Durham, and at that time the Wear may have joined the Tyne by way of the now obstructed and filled-in Team Valley. Evidence of the level of the sea during the Glacial Period is rarely available, but a 60-ft Raised Beach, possibly of interglacial age, has been recognized at Easington on the Durham coast.

POST-GLACIAL PERIOD

It is difficult to distinguish some of the post-Glacial from the Glacial deposits; for instance, some of our river terraces, which are usually classed with the former, appear to be closely associated with the latter. Furthermore, it is exceedingly probable that many of our Glacial deposits are of the same age

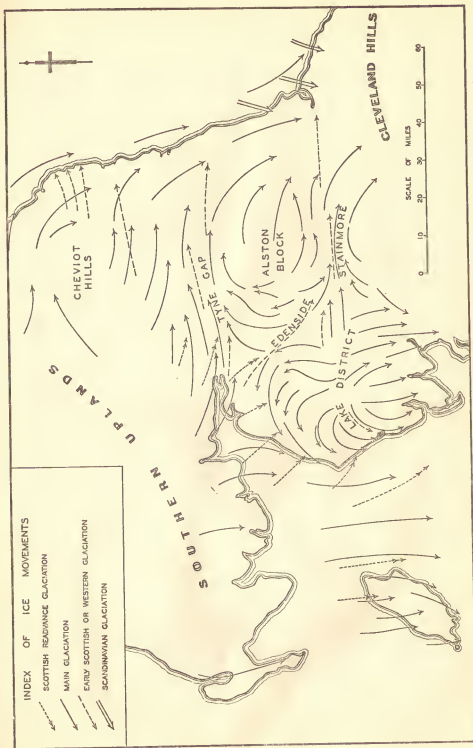


FIG. 26. Sketch-map showing the principal directions of ice movement during the glaciation of Northern England

as those considered to be post-Glacial in Southern England. With these reservations the post-Glacial deposits of Northern England may be dealt with regionally, viz. coastal and inland.

In the coastal areas they commence with the Submerged Forest, formed when the land lay higher, relatively to the sea, than at present. Relics of this forest, in the form of tree-stools and peaty material, etc., occur on the north-east coast at Howick, Amble, Seaton Sluice, Whitburn and West Hartlepool; on the Cumbrian coast in Allonby Bay and near Drigg; in Furness, and also in the Isle of Man. The state of the exposures is liable to variation, for storms in some cases temporarily uncover stretches of forest.

A period of submergence succeeded that of the forest growth, and the gravels of the so-called 25-Ft Raised Beach and its associated marine warps (silty clays) were accumulated. These deposits are well developed in the Isle of Man and in Cumberland, particularly along the shores of the Solway. No true raised beaches are known in Northumberland though occurrences have been noted in Durham at 140 ft above sea-level. Some of these 'beach' gravels contain *Cyprina islandica* and *Littorina littorea*, but the level of the deposits changes so rapidly that it seems more likely that they are sea-bottom material dragged across the coastal belt during the Glacial Period.

Sand dunes are not all of one age and some of them probably date back to dry periods of early post-Glacial times.

Inland, some of the earliest post-Glacial deposits were probably in part contemporaneous with the disappearance of the last traces of the ice-sheets. They include the scree in the hills, the material formed or deposited in the grading of the uneven valley floors left by the glaciers, and the silting up of many hollows. Some of the hollows were 'kettle-holes', which resulted from the melting of masses of ice incorporated in moraines. Although formerly the sites of tarns, such as may be seen south of St. Bees, many of these kettle-holes ultimately became peat bogs or mosses, as, for example, in the Bradford Kame in Northumberland, where the peat rests on a creamy shell-marl at one time in demand for agricultural purposes. Thick accumulations of peat generally occupy low ground, and some of these mosses or 'flows' in the Carlisle area are of large size, but much of the hill country is also peat-covered. Peat in the lowlands is still accumulating, whereas much of that on the hills is being eroded.

Some of the valleys have terraces at higher levels than the recent alluvium or flood plain, and occasionally these terraces may be linked up with the Raised Beaches.

One of the most interesting post-Glacial deposits is diatomite, which fills an old tarn hollow at Kentmere, near Kendal. This soft, clay-like rock is made up of the siliceous skeletons of microscopic plants; and may be used in the manufacture of lightweight sound and heat insulating bricks and in the preparation of dynamite.

X. MAPS, PUBLICATIONS, ETC., DEALING WITH THE DISTRICT

A complete list of publications dealing with the geology of Northern England is beyond the scope of the present work, but attention may be drawn to the following:

GEOLOGICAL SURVEY PUBLICATIONS¹

Quarter-inch to One Mile Maps

Colour-printed; 'Solid' edition. Price 9s. 0d. per sheet. Nos. 1 & 2, 3, 4 and 5 & 6

One Inch to One Mile Maps

Many of these are published both in 'solid' and in 'drift' editions. Each map bears two numbers. The first is that of the New Series; the second that of the Old Series hand-coloured geological map. Those marked with an asterisk are, or will be shortly, available as New Series colour-printed geological maps, price 6s. 6d. each.

1 (110 N.W.) Norham*; 2 (110 N.E.) Berwick upon Tweed*; 3 (110 S.W.) Ford*; 4 (110 S.E.) Holy Island*; 5 (108 N.E.) The Cheviot*; 6 (109 N.W.) Alnwick*; 7 (108 S.W.) Kielder Castle*; 8 (108 S.E.) Elsdon*; 9 (109 S.W.) Rothbury*; 10 (109 S.E.) Newbiggin*; 11 (107 N.E.) Longtown; 12 (106 N.W.) Bewcastle*; 13 (106 N.E.) Bellingham; 14 (105 N.W.) Morpeth*; 15 (105 N.E.) Tynemouth*; 16 (107 S.W.) Silloth; 17 (107 S.E.) Carlisle*; 18 (106 S.W.) Brampton*; 19 (106 S.E.) Hexham*; 20 (105 S.W.) Newcastle, Corbridge; 21 (105 S.E.) South Shields, Sunderland; 22 (101 N.W.) Maryport*; 23 (101 N.E.) Cocker-mouth*; 24 (102 N.W.) Penrith; 25 (102 N.E.) Alston, Weardale*; 26 (103 N.W.) Bishop Auckland*; 27 (103 N.E.) Durham, Hartlepool*; 28 (101 S.W.) Whitehaven*; 29 (101 S.E.) Keswick; 30 (102 S.W.) Appleby; 31 (102 S.E.) Middleton in Teesdale; 32 (103 S.W.) Barnard Castle, West Auckland; 33 (103 S.E.) Stockton, Middlesbrough; 37 (99 N.E.) Gosforth*; 38 (98 N.W.) Ambleside, Wastwater; 39 (98 N.E.) Kendal; 40 (97 N.W.) Kirkby Stephen; 47 (99 S.E.) Bootle; 48 (98 S.W.) Ulverston; 49 (98 S.E.) Grange over Sands; 58 (91 N.W.) Barrow; 36, 45, 46, 56, 57 (100) Isle of Man (in one sheet).

Six Inches to One Mile Maps

In regions of economic importance such as coal and iron fields many geological maps on the six-inch scale are now available to the public.

Vertical Sections

Sheets 29, 39, 41, 54, 60, 62, 66, 68, 75, 95.

Sheet, District and Economic Memoirs

(Those in course of preparation marked with an asterisk)

Berwick-on-Tweed and Norham (1926); Cheviot Hills and Ford (1932); Belford and Holy Island (1927); Alnwick (1930); Plashetts and Kielder (1889); Elsdon (1887); Rothbury (1936); Carlisle, Longtown and Silloth (1926); Brampton (1932); Tynemouth*; Maryport (1930); Cocker-mouth*; Durham*; Whitehaven and Workington (1931); Lake District, Northern Part of (1876); Appleby, Ullswater and Haweswater (1897); Gosforth (1937); Kendal, Sedbergh and Tebay (1872); Mallerstang (1891); Kirkby Lonsdale (1872); Furness (1873); Isle of Man (1903); Ore Field of Northern Pennines, vol. 1, 1948.

Special Reports on Mineral Resources

The following contain references to Northern England:

Vol. I, Tungsten and Manganese Ores (1915, ed. 3, 1923); Vol. II, Barytes and Witherite (1915, ed. 3, 1922); Vol. III, Gypsum and Anhydrite (1915, ed. 3, 1938); Vol. IV, Fluorspar (1916, ed. 4, 1952); Vol. V, Graphite, etc. (1916, ed. 2, 1917); Vol. VI, Ganister and Silica Rock (1918, ed. 2, 1920); Vol. VIII, Haematites of West Cumberland, etc. (1919, ed. 2, 1924); Vol. IX, Sundry Unbedded Iron Ores (1919); Vol. XIV, Fire-clays (1920); Vol. XXII, Lead and Zinc Ores, Lake District (1921); Vol. XXV, Lead and Zinc Ores, Northumberland and Alston Moor (1923); Vol. XXVI, Lead and Zinc Ores, Durham, etc. (1923); Vol. XXX, Copper Ores (1925); Iron-ore Field of South Cumberland and Furness (1941); Barium Minerals (1945).

¹Stocks of Survey publications were destroyed by enemy action; reprinting is in hand.

OTHER PUBLICATIONS

(Titles abbreviated in most cases)

General

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